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LRC WHEEL/RAIL INTERACTION AND SUSPENSION PROGRAM

(DSS CONTRACT OSD-00277)

FINAL REPORT

Prepared for

TRANSPORTATION DEVELOPMENT CENTRE
TRANSPORT CANADA

by

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December 1986

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LANGUAGE NOTICE Un sommaire en français de ce rapport est inclus avant la Table des Matières.

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Transport Canada / Transports Canada
Development / Développement

REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
TP8034E	6389	

4. Title and Subtitle	5. Report Date
LRC Wheel/Rail Interaction and Suspension Study Program	December, 1986.
	6. Performing Organization Report No.
7. Author(s)	8. Transport Canada File No.
David D. Taylor	D1465-456-2
9. Performing Organization Name and Address Bombardier Inc., Rail & Diesel Products Division 1505 Dickson St. Montreal, Que. H1N 2H7	10. DSS File No. 14SD.T8200-4-4575
	11. DSS or Transport Canada Contract No. OSD84-00277
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 200 Dorchester Blvd. West, Suite 601, West Tower Montreal, Que. H2Z 1X4	13. Type of Report and Period Covered
	14. Sponsoring Agency Code TDC 6389
15. Supplementary Notes	16. TDC Project Officer Sesto Vespa

17. Abstract

The VIA Rail LRC locomotives, with the CN modified Heumann wheel profile, became unstable after 20,000-30,000 miles of wear. The goal of this project was to understand the effect of wheel/rail interaction geometry on stability. Researchers tested a suspension modification, validated a non-linear computer model using field data and conducted a sensitivity analysis of LRC locomotive stability to rail inputs and suspension changes. Wheel and rail measurements were taken by CN Research, and were combined to provide effective conicity and contact angle data under stable and unstable (hunting) conditions. The computer model was successfully validated using this information. The main observations and conclusions are:

1) the LRC locomotive, with new type chevrons and yaw dampers, should be stable up to 120-130 mph;
2) effective conicity values in the 0.5 to 0.7 range were encountered;
3) no change in wheel profile is proposed.

The report also proposes a theory for the destabilizing effect of wear on the new CN modified Heumann profile and discusses means of further increasing the critical hunting speed of the locomotives.

18. Key Words	19. Distribution Statement
Wheel, rail, interaction, LRC, locomotives hunting, effective conicity, vehicle dynamics, suspension.	A limited number of copies are available from Transportation Development Centre.

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
Unclassified	Unclassified		

TDC CDT 79-005
Rev 86

Canada

Transports Canada / Transport Canada
Développement / Development

FORMULE DOCUMENTAIRE DU RAPPORT

1. N° du rapport Transports Canada	2. N° de l'étude — CDT	3. N° de catalogue du destinataire
TP 8034E	6389	

4. Titre et sous-titre	5. Date du rapport
LRC Wheel/Rail Interaction and Suspension Study Program	Décembre, 1986
	6. N° du rapport de l'organisme exécutant

7. Auteur(s)	8. N° de dossier Transports Canada
David D. Taylor	D1465-456-2

9. Nom et adresse de l'organisme exécutant	10. N° de dossier — ASC
Bombardier Inc., Division des produits ferroviaires et diesel 1505 rue Dickson Montréal, Qué. H1N 2H7	14 SD.T8200-4-4575
	11. N° de contrat — ASC ou Transports Canada OSD84-00277

12. Nom et adresse de l'organisme parrain	13. Genre de rapport et période visée
Centre de Développement des Transports 200 ouest, blvd. Dorchester, Suite 601, Tour Ouest, Montréal, Qué. H2Z 1X4	
	14. Code de l'organisme parrain TDC 6389

15. Remarques additionnelles	16. Agent de projet — CDT
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17. Résumé

Les locomotives du train LRC exploitées par VIA Rail, et équipées de roues à profil Heumann modifié par le CN (roues Heumann-CN) commencent à souffrir d'une instabilité de la marche au bout de 20 000 à 30 000 milles. La recherche visait à approfondir l'influence de la géométrie du contact roue-rail sur cette stabilité. Les chercheurs ont éprouvé une suspension modifiée, validé un modèle informatique tenant compte des paramètres non linéaires et fondé sur les données obtenues in situ, puis conduit une analyse de sensibilité des bogies aux variations dans les paramètres de marche. Le Centre de recherche CN Rail a procédé au mesurage des paramètres des rails et des roues, à partir desquels ont été calculées des valeurs de conicité effective et d'angle de contact, dans des conditions de marche tant stables qu'instables (lacet). Les résultats obtenus one confirmé la validité du modèle. Les principales constatations et les grandes conclusions de la recherches sont les suivantes:

1) La suspension modifiée et les amortisseurs anti-ballant favorisent la stabilité de la marche jusqu'à des vitesses de 120 à 130 mi/h.
2) Des valeurs de conicité effective entre 0,5 et 0,7 ont été constatées.
3) Aucune modification du profil de roue n'est proposée.

Le rapport propose une théorie expliquant l'effet déstabilisateur de l'usure des roues Heumann-CN ainsi que le moyen de relever davantage la vitesse critique du bogie, c'est-à-dire celle à partir de laquelle se manifeste le lacet.

18. Mots-clés	19. Diffusion
Roue, rail, interaction, LRC, locomotives, lacet, conicité effective, comportement dynamique, suspension.	Le CDT dispose d'un nombre limité d'exemplaires.

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
Non-classifié	Non-classifié		

Acknowledgments

The author gratefully acknowledges the assistance and co-operation received from Mr. Robert Bergner, Director of Locomotive Engineering, Bombardier Inc., R&DP Division, Dr. Nelson Caldwell, Ass't Chief of Technical Research, CN Research Center, Mr. Robert Radford, Chief Mechanical and Electrical Engineer, CN Rail, Mr. Robert Vadas, Senior Director of Engineering, Via Rail, and Mr. Harold List, Railway Engineering Associates.

Special thanks are also due to Dr. Caldwell and to Mr. Robert Young, Senior Design Engineer, Mechanical, Via Rail, for their valuable comments on the final draft of this report.

Summary

Hunting of the LRC locomotive trucks was observed three months after the locomotives entered revenue service in the summer of 1982. As a temporary solution, the wheel profiles were changed from the CN Modified Heumann, wide flange (WF) profile specified in the contract between Bombardier and Via Rail, to an AAR 1:40 WF profile. The new profile permitted stable operation but required remachining of the wheelsets every 50,000 miles (80,000 km) to ensure continued stability. An ongoing program was undertaken by Bombardier and Dofasco to determine the suspension modifications necessary to allow the locomotives to run stably on the Heumann profile until a normal wheel wear condemning limit was reached. This program consisted of the field testing and monitoring of two experimental LRC locomotives equipped with improved yaw dampers across the secondary suspension.

It was felt at the time that the fundamental effects of wheel/rail interaction geometry on the stability of the LRC locomotives were not fully understood. The locomotives were stable at low wheelset mileages, and became unstable after 20,000 to 30,000 miles (32,000 to 48,000 km) of wear. At the onset of instability, the vehicles were only unstable on certain sections of track. A second suspension modification, primary suspension chevrons stiffer in the longitudinal direction, had been identified by computer simulation as potentially stabilizing. Bombardier proposed the LRC Wheel/Rail Interaction & Suspension Study Program to the Transportation Development Centre (TDC) as a means of maximizing the learning experience of the ongoing testing, finding out more about the fundamentals of wheel/rail interaction geometry and its effect on vehicle stability, and testing the effect of the primary suspension modification (longitudinally stiffer chevrons) on stability. It was approved by TDC in late 1984 and started in March, 1985.

This program has involved the active co-operation of Via Rail and CN Research. Via Rail provided a third test locomotive and made the necessary arrangements for wheel machining and shop inspection. CN Research measured the rail profiles at two sites, where, respectivly, stable and unstable operation of the locomotives had been observed, and measured the wheel profiles on two LRC locomotives at various service mileages. They also produced the effective conicity and contact angle data. Bombardier managed the project, selected the rail sites and the wheel profile measurement mileages, analyzed the data, conducted a truck stability sensitivity analysis, and wrote the three project interim reports and the final report.

The principal results and conclusions are listed as follows;

i) the DYNSIM computer model, obtained by Bombardier, was

shown to realistically model the field performance of the LRC locomotive, based upon the rail and wheel profiles measured.

ii) large values of effective conicity were developed by combining the wheel profile and the unloaded track profile measurements. Worst case conicities of 0.69 were found, but they were based upon simulated worn wheel profiles that were applied to one of the test locomotives, and may be suspect. Average conicities of 0.5 were developed, based on service worn wheel profiles. Both values are higher than those typically used by North American truck designers.

iii) the locomotives were initially stable because of two point contact between the wheel and the rail. Conicities increased rapidly as the profiles became conformal with wear. It is proposed that there may be a transition phase between two point and fully conformal contact that is more destabilizing than the fully conformal condition.

iv) the present LRC suspension, with new chevrons and Koni yaw dampers, is predicted by the DYNSIM computer model to be stable to between 121 and 132 mph (195 to 213 km/h) with effective conicities of 0.69 and 0.50 respectively. This should provide a good margin of stability over the present top operating speed of 95 mph (153 km/h). It is also shown that additional stability gains could be made by further increasing the longitudinal primary suspension stiffness and the yaw damping, provided that suitable hardware could be found, and that the many other requirements of the suspension, especially wheel unloading and curving, could continue to be satisfied.

v) continued use of the CN Modified Heumann profile is recommended.

vi) one of the sites measured had asymmetric rail head profiles, which resulted in high conicity values and a lateral offset of the equal rolling radius position of the wheelsets. The cause of this is not yet fully understood.

vii) Via Rail are currently equipping the LRC locomotives with the new chevrons and yaw dampers described in this report. It is recommended that Via Rail; a) use the CN Modified Heumann wheel profile on the LRC locomotives that have been so equipped, b) stop remachining the wheel profiles every 50,000 miles (80,000 km), and c) begin a program of monitoring the modified vehicles for stability and measuring the wheel profile changes with increasing wear. The monitoring and test program will establish if periodic machining of the profiles will be required to insure continued stability, or if the wheelsets can remain in service until normal wear limits are reached. It is likely that Via Rail can now begin to take full advantage of a conformal profile, and substantially reduce wheel maintenance costs.

Sommaire

Les bogies équipant les locomotives du train LRC ont commencé à souffrir du défaut appelé lacet quelques mois après leur mise en service payant à l'été de 1982. A titre de solution provisoire, le profil des roues a été changé, passant du profil Heumann-CN boudin large prévu dans le contrat entre Bombardier Inc et VIA Rail, à un profil AAR caractérisé par une conicité 1:40. Ce dernier est favorable à une bonne stabilité de marche, mais il faut procéder au tournage des roues à intervalles de 50 000 milles (80 000 km) afin de garantir cette stabilité. Un programme permanent de recherche a été lancé par Bombardier et Dofasco dans le but de déterminer les modifications à apporter à la suspension pour assurer la stabilité de marche de la locomotive équipée de roues à profil Heumann, jusqu'à ce que celles-ci atteignent la hauteur limite de boudin justifiant leur retrait. Ce programme prévoyait des essais en service de deux locomotives LRC équipées d'amortisseurs anti-lacet posés transversalement dans la suspension secondaire.

A l'époque, on ne connaissait pas très bien la relation fondamentale entre géométrie du contact roue-rail et stabilité de marche des locomotives LRC. On constatait seulement que, de stable au départ, elles devenaient instables au bout de 20 à 30 000 milles (32 à 48 000 km), mais que l'instabilité ne se ressentait que sur certain tronçons de voie. Une solution possible, dégagée par voie de simulation informatique, consisterait à augmenter la raideur longitudinal des "chevrons" dans la suspension primaire. Bombardier a donc proposé un nouveau programme dans le but de tirer tout le parti possible de l'expérience acquise grâce au programme permanent, à savoir, découvrir la relation fondamentale entre géométrie du contact roue-rail et stabilité de marche et, en même temps, chiffrer l'effet sur cette stabilité de marche de la raideur accrue donnée à la suspension primaire. Ce programme a été approuvé par le Centre de développement des transports vers la fin de 1984 et lancé le mois de mars suivant.

Via Rail et le Centre de recherche du CN ont collaboré activement à ces travaux, la première fournissant une troisième locomotive destinée aux essais et faisant faire le profilage des roues et leur inspection en atelier. Quant au Centre de recherche, il a mesuré le profil des rails à deux endroits où une marche respectivement stable et instable avait été signalée et, à intervalle régulier, le profil des rous des deux locomotives LRC. Ils ont aussi rassemblé les données permettant de calculer la conicité effective des essieux ainsi que les angles de contact. Pour sa part, Bombardier a géré le program, sélectionnant les trouçons où le profil des rails devait être mesuré, déterminant les intervalles de mesurage du profil des roues, analysant les données, conduisant une analyse de

sensibilité des bogies aux variations dans les paramètres de marche et, enfin, rédigeant les trois rapports provisoires ainsi que le rapport définitif.

Les principaux résultats du programme ainsi que ses grandes conclusions ont été les suivants:

i) Le modèle informatique appelé DYNSIM, obtenu par Bombardier, rend compte de façon très réaliste du comportement de la locomotive LRC à partir des données géométriques des rails et des roues concernés.

ii) Des valeurs élevées de conicité effective ont été mises en évidence en combinant les mesures caractérisant un profil de roue et un profil de rail sous charge nulle. Dans le cas le plus défavorable, une valeur de 0,69 a été dégagée, mais comme elle est fondée sur des roues à profil d'usure reconstitué équipant l'une des locomotives d'essai, il y a lieu de s'en méfier. Par contre, une valeur moyenne de 0,5 a été dégagée, en partant de profils d'usure de roues résultant de conditions réelles de service. Quoi qu'il en soit, ces deux valeurs restent quand même plus élevées que les valeurs types retenues par les concepteurs de bogies en Amérique du Nord.

iii) La stabilité initiale des locomotives s'explique par le phénomène de bicontact entre la roue et le rail. La conicité augment rapidement à mesure que le profil de la roue s'approche de celui du rail. Il est suggéré qu'entre cette situation de bicontact et la situation d'usure à profil "conformel", il existe une phase de transition qui serait plus déstabilisante que celle-ci.

iv) Le modèle informatique a montré que la suspension actuelle du LRC, dotée de "chevrons" à raideur longitudinale accrue et d'amortisseurs anti-lacet Koni, favourise la stabilité de la marche entre 121 et 132 mi/h (195 et 213 km/h), la conicité effective correspondante étant de 0,69 et 0,50, respectivement. La marge de sécurité est ainsi accrue par rapport à la vitesse maximale de service qui est actuellement de 95 mi/h (153 km/h). Le modèle informatique montre, en outre, que de nouveaux gains de stabilité pourront découler d'un renforcement tant dans la raideur longitudinale de la suspension primaire que dans le taux d'amortissement transversal, à la condition de trouver des éléments de suspension appropriés, qui ne modifient pas les nombreuses autres caractéristiques de la suspension, notamment en ce qui concerne le délestage des roues et leur inscription en courbe.

v) Il est proposé de s'en tenir au profil Heumann-CN.

vi) Sur un des tronçons où le profil des rails avait été mesuré, des résultats asymétriques ont été obtenus, se

traduisant par des valeurs élevées de conicité et par un décalage transversal de la position à laquelle la différence des rayons de roulement devient nulle. Les raisons n'en sont pas encore parfaitement connues.

vii) Via Rail a entrepris d'équiper les locomotives LRC des "chevrons" à raideur longitudinale accrue et des amortisseurs anti-lacet, décrits dans ce rapport. Il est recommandé que VIA Rail;

a) équipe de roues à profil Heumann-CN les locomotives LRC modifiées dans le sens indiqué,

b) cesse le tournage des roues tous les 50 000 milles (80 000 km), et

c) lance un programme de suivi des locomotives ainsi modifiées pour en déterminer la stabilité de marche et pour connaître l'évolution du profil des roues au fur at à mesure qu'elles s'usent en service. Grâce à ce double programme de suivi et d'essais, il sera possible de déterminer si le tournage périodique des roues est encore nécessaire pour garantir la stabilité de marche ou bien si on peut les maintenir en service sans intervention jusqu'à ce que les limites d'usure en service normal aient été atteintes. Il semble que VIA Rail peut commencer dès maintenant à tirer le plein parti d'un profil d'usure "conformel", débouchant sur une réduction sensible du coût d'entretien des roues.

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II	Interim Report # 1 "LRC Primary Suspension Modification Test, Sept.29, 1985"
III	Interim Report # 2 "Literature Review Report"
IV	Interim Report # 3 "Wheel and Rail Profile Measurements and Effective Conicity and Contact Angle Development"
V	LRC Locomotive - Basic Truck & Suspension Parameters
VI	S.P.E.C. Session Output

1.0 Introduction

The LRC locomotive is a high speed, diesel electric locomotive designed and built by Bombardier Inc. The first prototype was built in 1974. Two units were leased to Amtrak in 1980, and a total of thirty-one units were sold to Via Rail in the early 1980's. The locomotive trucks were designed and built by Dofasco Inc. The trucks began to develop unstable hunting oscillations three months after being placed into revenue service in the summer of 1982. The hunting was related to a change in wheel profile, from the AAR 1:40, narrow flange (NF) profile used on the Amtrak locomotives, to the CN Modified Heumann, wide flange (WF) profile, used on the Via Rail units. The CN Modified Heumann profile specified in the contract is a conformal profile. This type of profile gives the longest wheel life, providing that stability can be maintained. A temporary solution, using a 1:40, WF, profile was immediately implemented on a fleet wide basis. The drawback to this solution was that the profile had to be remachined every 50,000 miles to insure continued stability.

While the temporary solution was being implemented, a program to determine a permanent solution, that would allow stable operation with the CN Modified Heumann profile, was initiated. It was apparent during the course of this investigation that not enough was known about the effects of wheel/rail interaction geometry and of vehicle suspension on vehicle stability. An application was made to the Transportation Development Centre (TDC), by Bombardier, for funding for a program to conduct further research in these areas. The project was approved in the fall of 1984, and became active in early 1985.

This report, the final report for the project, describes the work done in the areas of stability monitoring, high speed vehicle testing, wheel and rail profile measurement, effective conicity determination, and theoretical analysis. The following three interim reports have already been prepared and issued;

Interim Report # 1:	LRC Primary Suspension Modification Test (issued February 1,1986)
Interim Report # 2:	Literature Review Report (issued March 7,1986)
Interim Report # 3:	Wheel and Rail Profile Measurements & Effective Conicity and Contact Angle Development(issued September 1,1986)

All three reports are appended.

A complex, non-linear, time integrated computer model (DYNSIM) was obtained from Railway Engineering Associates Inc., and was commissioned, validated, and used for the theoretical analysis portion of the work.

One change was made to the project, as defined in the Work Statement, as it evolved. An experimental set of primary suspension dampers, stiffer in the longitudinal direction, was to have been installed on the locomotive assigned to the project by Via Rail (Unit 6925). There were two other locomotives under truck suspension test with Via at this time as well. They were both equipped with new secondary suspension yaw dampers, which, it was hoped, represented a technical solution to the hunting problem. One of these locomotives (Unit 6930) began to hunt again in the summer of 1985. It was concluded that the yaw dampers alone were not sufficient to resolve the hunting problem. At this point, the decision was taken to install the new chevrons on Unit 6930, thereby rendering them unavailable for Unit 6925. Unit 6930 was then incorporated into the TDC project and its wheel profiles were measured. The TDC project actually benefited from this, as 6930 was tested above normal operating speeds as part of the ongoing Bombardier/Via tests, and the results of these high speed tests were available to it. This is described in more detail in the body of the report.

2.0 Summary of Physical Testing

2.1 Monitoring of LRC Test Unit 6925

Locomotive Unit 6925 was assigned to this program by Via Rail. It had its wheels machined to the CN Modified Heumann profile on August 6, 1985, and was released into revenue service. Its suspension was identical to that of the rest of the fleet, which was running on the AAR 1:40,WF, wheel profile to insure stability. Suspension details are givn in Appendix V. Based on past experience, it was expected that this unit would begin to hunt after 20,000 to 30,000 miles (32,000 to 48,000 km) of service. At this time, the new primary suspension would be installed, and a non revenue road test conducted to establish the effect of the chevrons on stability. A monitoring program was undertaken to establish the point at which instability first appeared.

Signs of instability were first recorded on Dec.18,1985 after approximately 40,000 miles (64,000 km) of service. CN Research measured the wheel profiles at zero mileage (Aug.8,1985) and at 50,000 miles (80,000 km) (Jan.20,1986). According to the program plan, the new chevrons should have been applied at this time. However, as previously explained, the chevrons had already been applied to Unit 6930. Unit 6925 had its wheelsets remachined to the AAR 1:40, WF, profile, and was returned to unmonitored revenue service.

Figures 1 and 2 illustrate sample accelerometer traces for the unit at 0 mileage (stable) and at 40,000 miles (64,000 km) (conditionally stable). It should be noted that, even at 40,000 miles, the unit was stable almost all of the time. The sample shown in Figure 2 is the worst of only several such bursts of sub-hunting activity recorded.

2.2 High Speed Test - LRC Unit 6930

The new chevrons, stiffer in the longitudinal direction, were installed on Unit 6930,in September, 1985. The locomotive was tested at speeds of up to 103 mph (166km/h), with no signs of instability, on September 29, 1985. The test was limited in speed by the activation of the overspeed limit on the locomotive.

A second unit, Unit 6923, was also tested on the same day. It was equipped with the new Koni yaw dampers, but had conventional chevrons. It showed several bursts of marginal hunting activity at 103 mph (166km/h), although no clearly identified occurrences of hunting were encountered. This test is described in Interim Report # 1 (Appendix II).

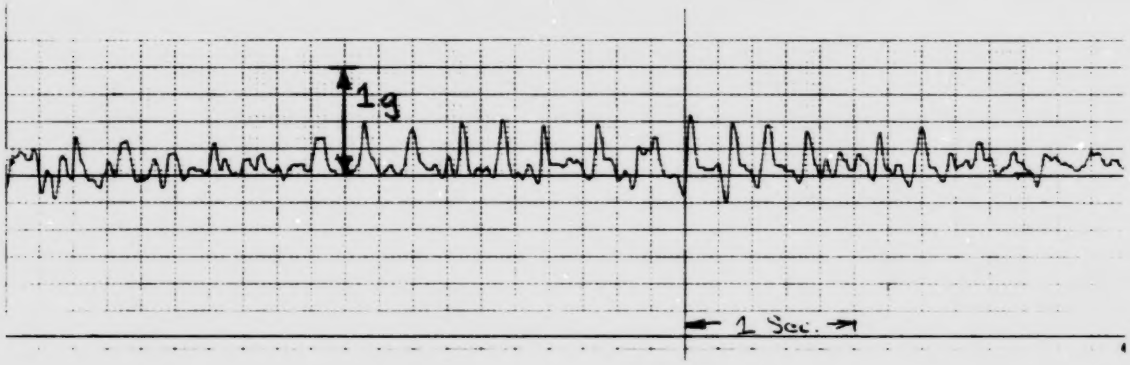

Figure 1 Unit 6925 - Initial Test Run - 0 Miles (0 km)

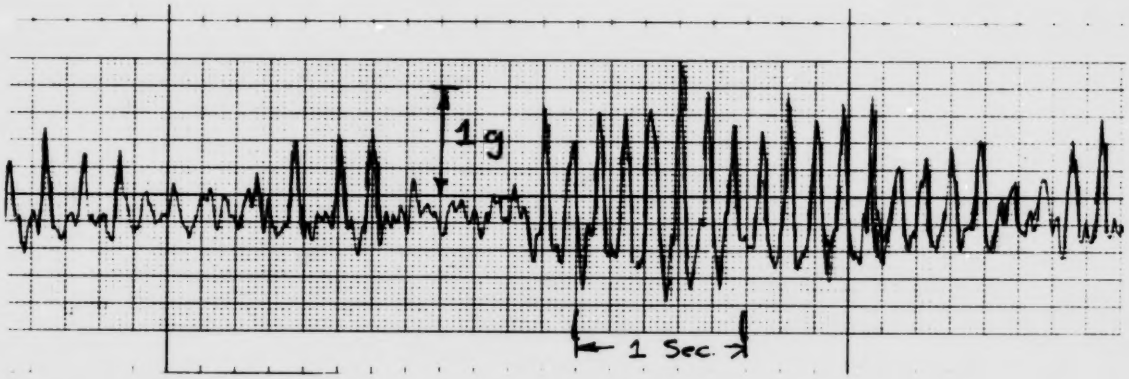

Figure 2 Unit 6925 - Conditional Stability - 40,000 Miles (64,000 km)

Both of these units had a profile simulating 30,000 miles (48,000 km) of wear with the CN Heumann Profile applied to them in July, 1985. This was done to salvage the test program, after the profiles had been remachined because of thermal cracks in the wheels. A special template was prepared by Bombardier for this purpose, based upon wheel measurements taken on Unit 6930 at 30,000 miles (48,000 km) using a pencil trace measurement (see Interim Report #1, Appendix II). The 46,000 miles (74,000 km) of wear on Unit 6930 , on the test day, was comprised of the 30,000 miles (48,000 km) of simulated wear and an additional 16,000 miles (26,000 km) of actual wear. The corresponding figures for Unit 6923 are 50,000 miles (80,000 km) of wear, comprised of 30,000 miles (48,000 km) of simulated wear and 20,000 miles (32,000 km) of actual wear.

2.3 Wheel/Rail Profile Measurements

One of the principal goals of the program was to find out more about wheel/rail interaction geometry and its effect on vehicle stability. Of particular importance were: how the CN Modified Heumann Profile changed with wear; and why hunting occured on certain sections of track and not on others. A sub-contract was awarded to CN Research to measure selected wheel and rail profiles, and to develop the effective conicities from the measured data. The schedule of measurements was as follows:

Locomotive Wheel Profile Measurements

Locomotive Unit No.	Suspension Configuration	Details
6925	standard	- zero mileage (Aug.8,1985). - at release into revenue service.
6925	standard	- 50,000 miles (80,000 km) (Jan.20,1986). - after onset of instablity.
6930	new yaw dampers & new chevrons	- 66,000 miles (106,000 km) (Dec.6,1985). - unit stabilized by chevron change at 46,000 miles (74,000 km). - profile at 46,000 miles (74,000 km) interpolated from this data.

Track Profile Measurements
(measurements taken with track unloaded)

Site Milege	Rail	Installation Date	Details
MP 77.5	Sydney 132# RE Sept.'82	1983	- typical of track where vehicles were always stable. - measured December 10,1985.
MP 165.56	Sydney 132# RE Oct.'84	June-July 1985	- site of worst instability of Unit 6930 in August,1985. - measured October 28,1985.

Measurement of the rail movement under load had been considered at the planning stage of the project, but was eventually dropped for budgetary reasons. The measurements, together with the corresponding effective conicity development, are described in Interim Report #3 (Appendix IV) and in the CN Research Final Report (1).

It is noted that the track where the instability occurred was recently laid. This effect, that newly laid track seemed to induce instability, had been frequently observed throughout the LRC locomotive stability testing program, going back to 1982.

A second site inspection at MP 77.5 & 165.56 was made on October 15, 1986, after analysis of the data had shown a possible asymmetry of the rail head with respect to the base. No such asymmetry was found.

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(1) Experimental Determination of Wheel/Rail Geometry Interaction of LRC Locomotives with CN Heumann Profiled Wheels, Mr.O. Szklar, Project Engineer, CN Rail Research Centre, July 21, 1986.

3.0 Summary of Effective Conicity & Contact Angle Data

3.1 Averaged Field Data

3.1.1 Averaged Data

The CN Research Final Report for this project contained 32 sets of data relating to the change in rolling radius and contact angle difference with lateral offset of the wheelset. These represented the combinations of four locomotive sets of wheel profiles, two sets of track profiles and four wheelsets per locomotive. The arithmetic averages of this data, for individual locomotives at the two rail sites, have been determined and are shown in Figures 4,5 and 6 of Interim Report # 3 (Appendix IV).

3.1.2 Asymmetric Data

All of the graphical data sets in the CN Research Final Report for MP 165.56 showed clear evidence of a lateral offset of the zero crossing. The track at this site had been laid four months before the measurements were taken. The tendancy was worse for Unit 6930 than for Unit 6925. Some lateral offset of the zero crossing was also apparent for Unit 6930 at MP 77.5. Two figures are shown here to illustrate this phenomenon. Figure 3 shows the data for Unit 6925 (50,000 miles) at MP 77.5 and MP 165.56. It is seen that there is no lateral offset at MP 77.5, but there is at 165.56. Figure 4 shows the data for Unit 6930 (46,000 miles), at MP 77.5 and MP 165.56. Here, it is apparent that there is some offset at MP 77.5 and more at MP 165.56. Two conclusions are drawn;

i) the reprofiling of the wheelsets of Unit 6930 with the 30,000 miles (48,000 km) simulated profile introduced some asymmetry into the wheelsets that may have artifically increased the conicity.

ii) there was asymmetry present in the track profiles at MP 165.56 that resulted in lateral offset of the zero position for both vehicles.

A second visit was made to both rail sites on October 15, 1986, to verify if there was any asymmetry in the rail head with respect to the base. No such asymmetry was found. The source of the asymmetric behavior is not fully explained, and is felt to be beyond the scope of the present study. It is likely due to the new condition of the rail head, a condition that had modified with wear. The measuring and data processing techniques have been reviewed at length with CN Research, and it

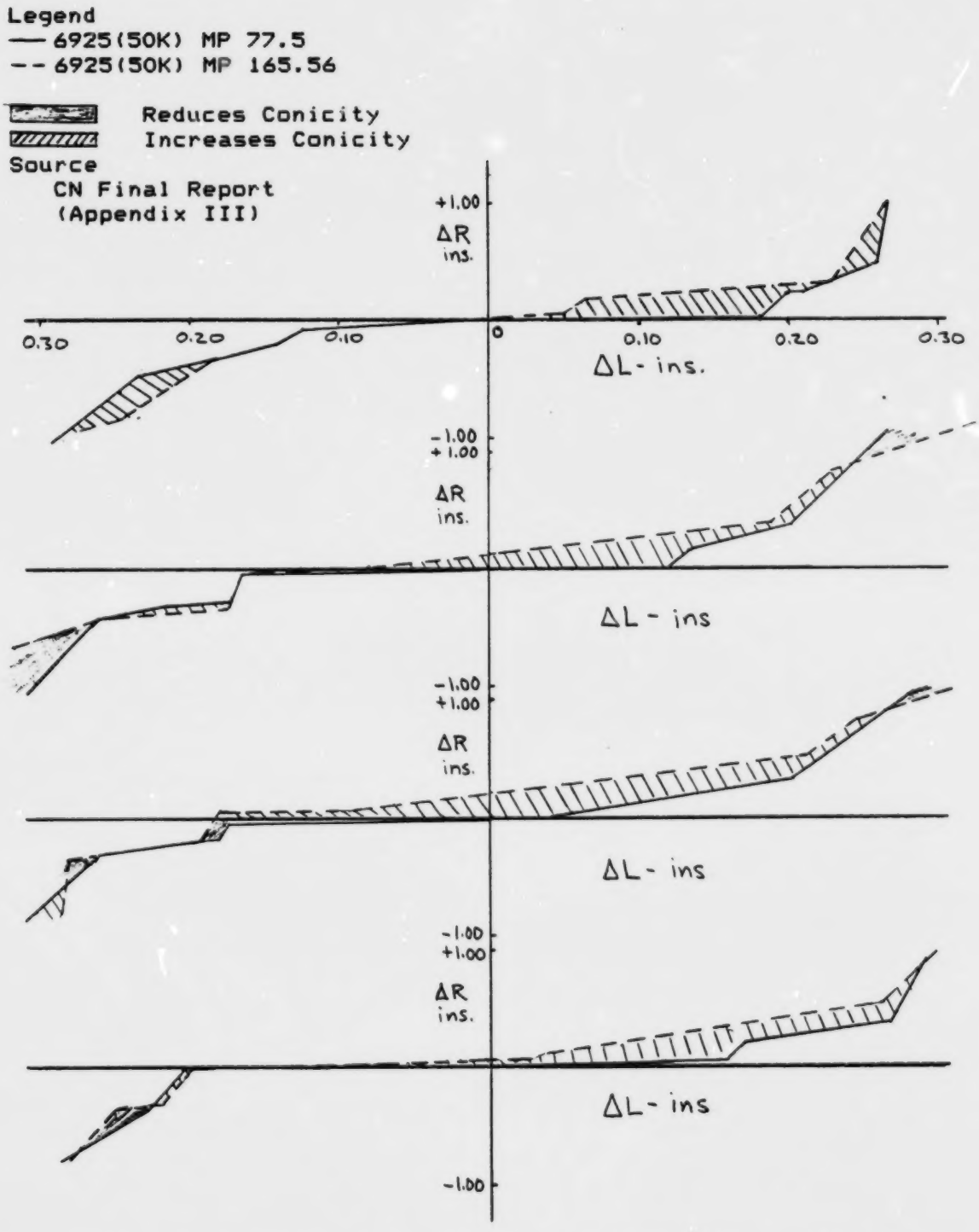


Figure 3 Lateral Offset of Zero Rolling Line - Unit 6925

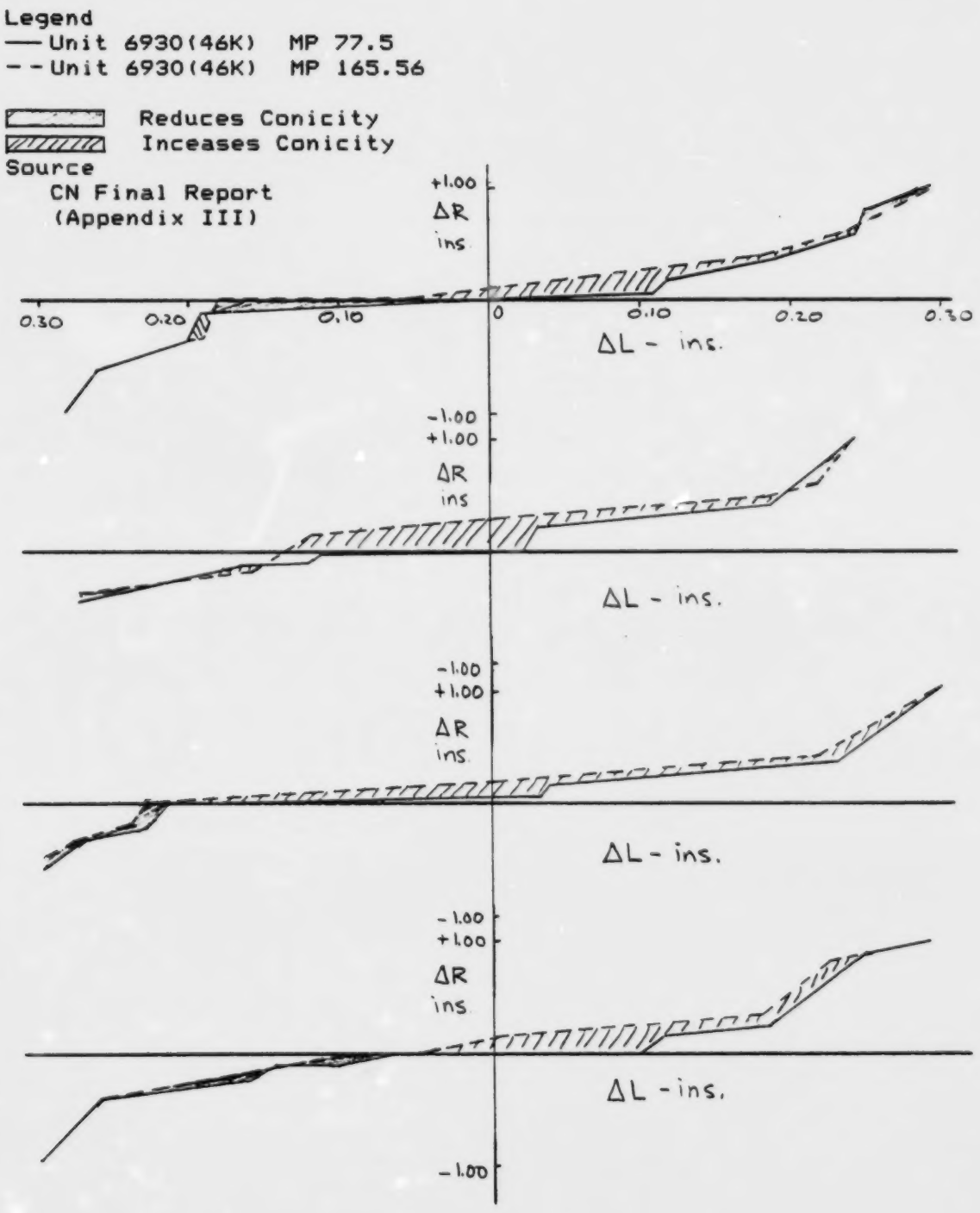


Figure 4 Lateral Offset of Zero Rolling Line - Unit 6930

is felt that the data, and the resulting effective conicity values, are valid.

3.2 Test Data Used in Model Validation

Two changes in performance of the test locomotives were recorded during the program. Unit 6925 was stable with friction yaw snubbers at zero mileage and became conditionally stable on certain sections of track after 40,000 miles (64,000 km) of wear. Unit 6930, equipped with new hydraulic yaw dampers unexpectedly became unstable over a section of track after 46,000 miles (74,000 km) of wear, and was stabilized by the addition of new chevrons, stiffer in the longitudinal direction (see Sect.2.2). Wheel and rail profiles were recorded by CN Research to capture these changes of performance. Average values of change in rolling radius and contact angle with lateral offset were determined for both cases. This data was used as input to validate the DYNSIM computer model (see Section 4.2). The two data sets, together with the appropriate track mileage and suspension data, form Figures 7&8 of Interim Report # 3 (Appendix IV). Axles 1&2 and Axles 3&4 were separated in the averaging process for Unit 6930, because only the front truck of the unit was hunting. The locomotive was running backwards in the trailing position, so that it was the last truck in the train consist that was hunting. It was not possible to repeat the test with the unit leading, to determine if the directionality was a factor.

3.3 Conicities Used for the Sensitivity Analysis

Three sets of conicity and contact angle difference data were established, based upon the test data. In the cases where lateral offset of the zero crossing was evident, the rolling radius difference at the center position (L=0) was taken as the zero for the vertical scale. In this way, the slope, or conicity, was modeled, but the offset was not. This was necessary, as the DYNSIM model cannot accomodate differences in size, or in profile geometry, between the right and left wheels. These data sets, together with a nominal data set, are described as follows;

i) Worst Case

The worst case data is the average data for all wheelsets of Unit 6930 (46,000 miles), at MP 165.56. This data may not be representative because of a possible manufacturing error in the templates used to machine a simulated 30,000 mile (48,000 km) profile on these wheelsets (see Section 2.2).

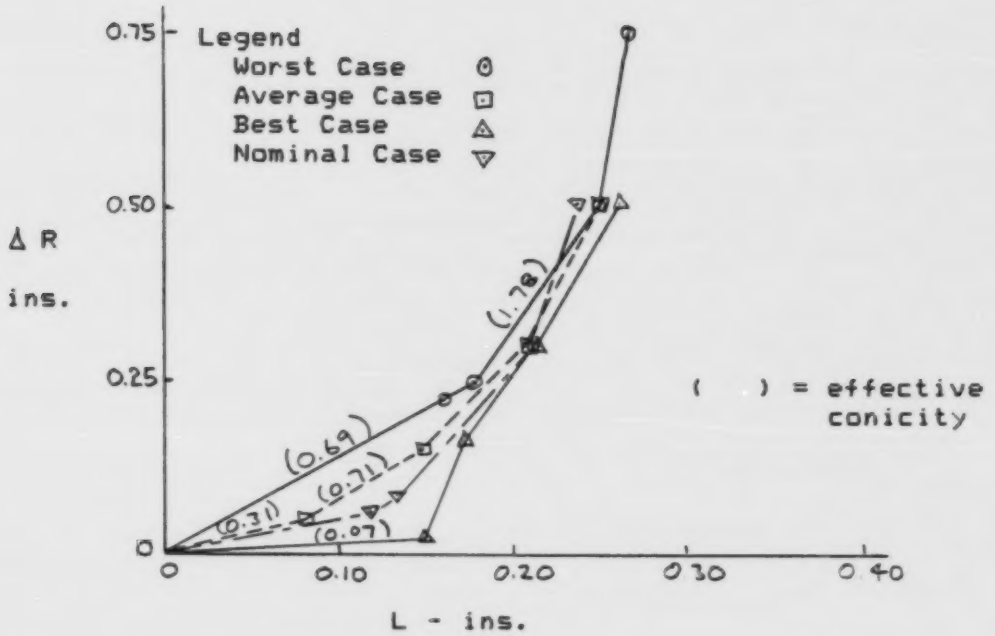


Figure 5A Change in Rolling Radius vs. Lateral Offset

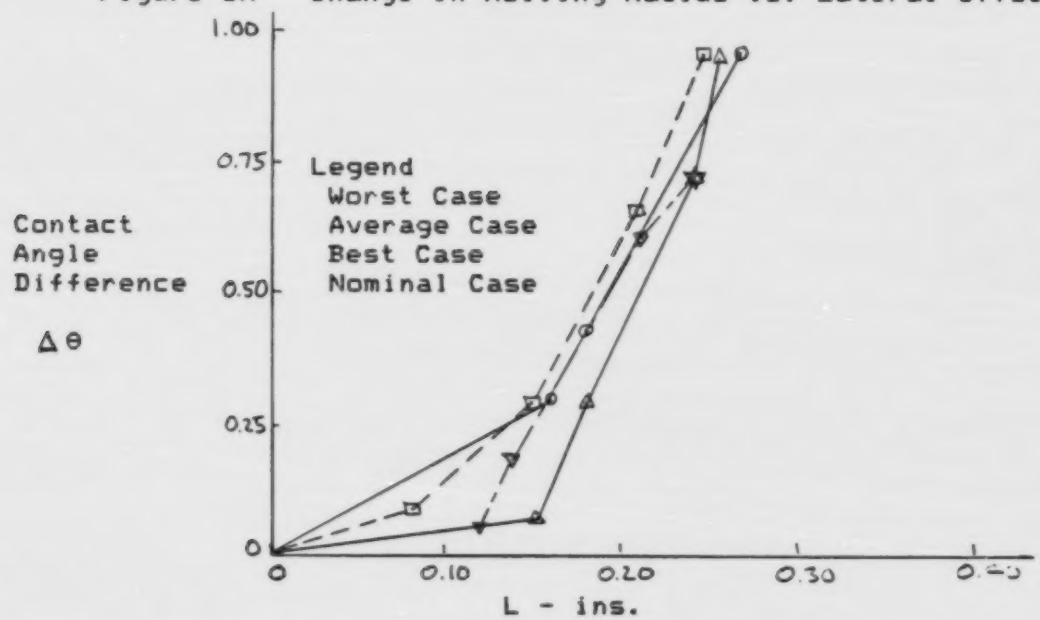


Figure 5B Difference in Contact Angle vs. Lateral Offset

Figure 5 Nominal Values of Conicity and Contact Angle Difference Used in Sensitivity Analysis

ii) Average Case

The average case data is the average data for all wheelsets of Unit 6925 (50,000 miles) at MP 165.56 and of Unit 6930 (46,000) at MP 77.5. The two data sets were very similar.

iii) Best Case

The best case data is the average data for all wheelsets of Unit 6925 (50,000 miles) at MP 77.5.

iv) Nominal Conicity

The nominal data combines the theoretical new CN Modified Heumann profile wheel with the theoretical new 132 # RE rail (Figure LRC #34, CN Research Final Report).

No data sets were developed for the zero mileage data, because the locomotives are stable to very high speeds at the very low effective conicities that this data represents. The four data sets are plotted graphically in Figure 5.

3.4 Change in Conicity With Wear

One of the aims of the program was to establish the process by which the locomotives, running with the CN Modified Heumann profile, were initially stable, and became unstable after 20,000 to 30,000 miles (32,000 to 48,000 km) of service. Zero mileage readings were available for Unit 6925, and it was used in this exercise. MP 77.5 was selected because of the symmetry of the data at this location. The change in rolling radius versus lateral offset data for this unit at 0 and 50000 miles (80,000 km) at MP 77.5, are shown in Figure 6.

It is apparent from the low conicities at zero mileage shown in Figure 6 and by overlaying the wheel and rail profiles (not shown here) that there is initial two point contact. Under two point contact conditions, the wheel contacts the rail at two distinct positions symultaneously; in the tread area, where most of the weight is reacted, and in the flange area, where most of the lateral forces are reacted. There is a protected zone in the flange root area of the wheel that does not contact the rail. With further wear, the wheel and rail profiles become conformal, the protected area comes into contact with the rail, and single point contact is established. This two point contact is initially stabilizing, because the point of rolling contact is, in effect, forced to stay in the low conicity center area of the tread by the lack of conformity. With a fully conformal profile, the contact patch between the wheel and the rail moves

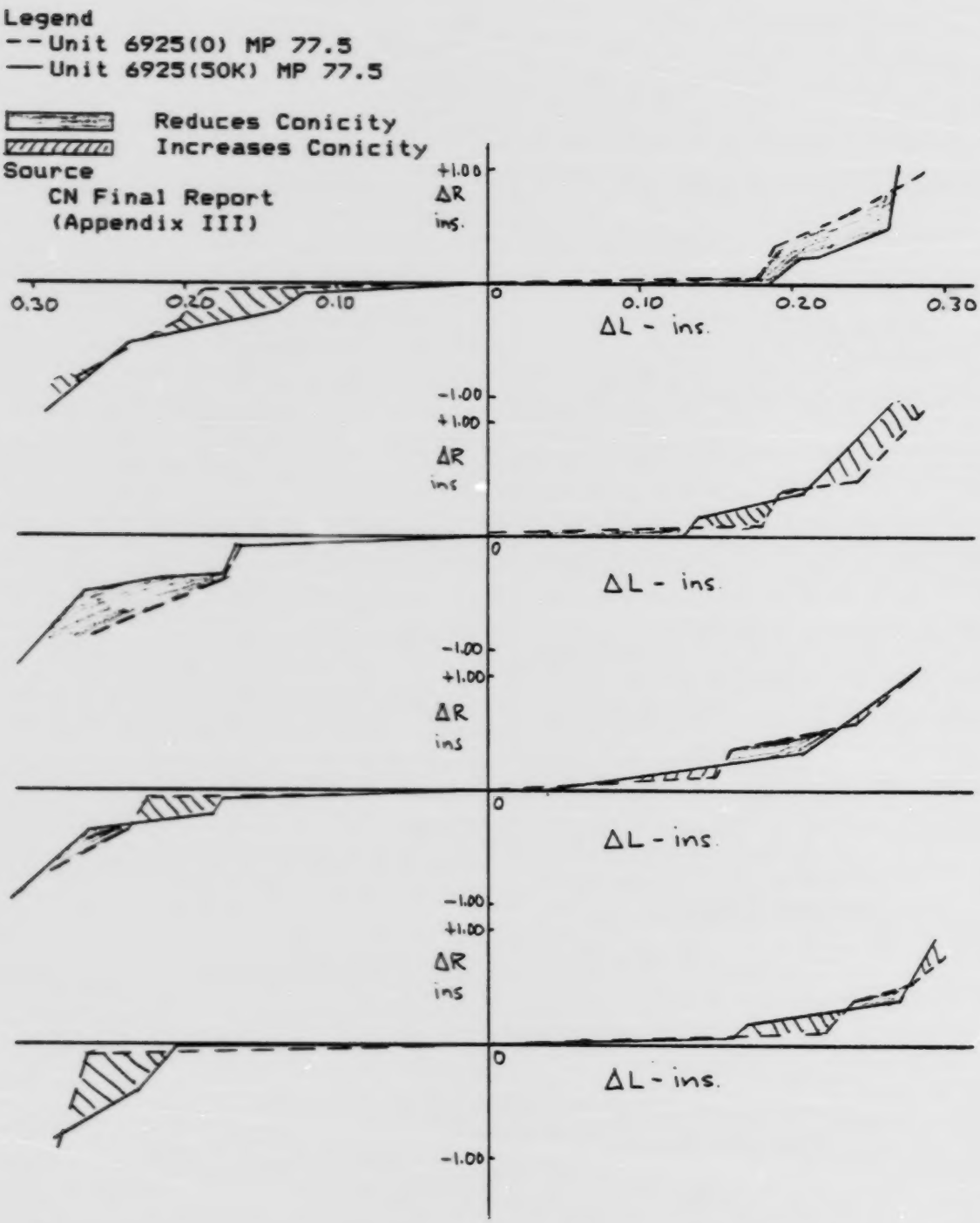


Figure 6 Change in Conicity with Wear - Unit 6925 @ MP 77.5

rapidly outward, in a non-linear fashion, with lateral motion of the wheelset. This results in large changes in rolling radius, and large values of conicity.

It is proposed, upon examination of the data, that the breaking-in period during which the wheel becomes conformal with the rail, may involve passing through a transitional phase where the conicity values become even more de-stabilizing. For six of the eight directional data sets represented in Figure 6, there is a step increase in the change of rolling radius in the running zone. These increases correlate well with the wheel wear patterns shown in Figures 9, 10, 11, & 12, of Interim Report #3 (Appendix IV). Where there is an increase in rolling radius change in the running zone, there is an area of very low, or zero, wear in the tread near the flange root, of the wheel whose flanging is represented in that data set. This is, in all cases, accompanied by some flange wear. This area of zero wear is protected by the two point contact between the wheel and the rail, and does not contact the rail until sufficient wear has occurred in the initial contact areas. Keeping the contact patch in the tread center initially gives low values of conicity, but, with wear, causes a ridge of unworn wheel metal to form in the protected area of the tread. When this protected area begins to contact the rail, because of wear in the other areas,there is a step increase in the running radius of the wheel at this point. It is proposed that this wear pattern causes the step change in rolling radius that is apparent in six of the eight data sets of Figure 6. It is expected that this effect will diminish with wear, and the conicity will stabilize under fully conformal conditions.

The reader is cautioned that this mechanism is not definitely proven by the data, and is presented here as a theory that others may wish to consider.

3.5 Discussion of Effective Conicity Findings

The averaged changes in rolling radius with lateral motion for the worst, average and best cases, together with the theoretical new wheel and new rail curve, are shown in Figure 5 (see Section 3.3). The effective conicities represented are shown in brackets on the curves.

The averaged conicity values, based upon the data illustrated in Fig. 5 are shown below. They are average values over a lateral displacement range of +/- 0.150 inches, and may not be identical to the values shown in Fig. 5.

Data Set	Effective Conicity
Worst Case	0.69
Average Case	0.50
Best Case	0.07
Nominal Case	0.40

The worst case data may not be valid because of the possibility that an error was machined into the wheelsets of Unit 6930 when the simulated 30,000 mile profile was applied (see Section 2.2). Even ignoring this, there is still an effective conicity value of 0.50 for the average case. This is a surprisingly high value that was not forseen by the original vehicle designers. It is not without precedent, however,as the Literature Survey (Interim Report #2, Appendix II) located several references to values as high as this in mainline track in England and Germany.

Another surprising result is that the best case effective conicities are lower than the nominal case values. A study of Figures LRC 33 and LRC 34, from the CN Research Final Report would indicate that this is due to the rail profile rather than the wheel profile. The indication is that the worn rail profile at MP 77.5, gives lower effective conicities than the nominal new profile.

4.0 Mathematical Analysis

4.1 DYNSIM Computer Model

The mathematical analysis work that has been done has made use of the DYNSIM computer model, acquired by Bombardier from Railway Engineering Associates. It is a fully non-linear program that realistically models all of the suspension elements and the wheel/rail geometry inputs. The wheel/rail interaction geometry can be modelled in a piece-wise linear fashion with as many steps as required. This enables modelling of the contact angle differences and changes in rolling radius with great accuracy.

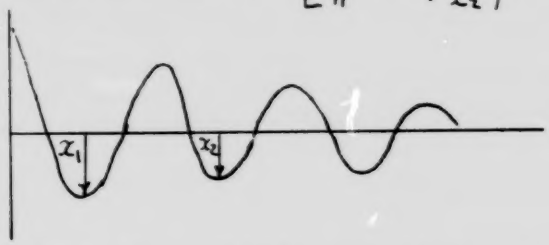
This model was used in the original work that was done, in the spring of 1983, to define a permanent solution to the hunting problem on these locomotives.

4.2 Model Validation

4.2.1 Definition of Stability

Stability was defined mathematically in terms of the damping coefficient for the first two cycles. This is illustrated in the following sketch;

Damping Coefficient = $\frac{1}{2\pi} \ln\left(\frac{x_1}{x_2}\right)$



In running the model, the vehicle was given an initial lateral offset that exceeded the flangeway clearance, at a selected speed. The model was then run for one second of real time. As the hunting frequency is approximately five Hertz, this was considered to be adequate. The lateral motion of the vehicle would either stabilize or continue to oscillate. Whenever the damping coefficient for the first two cycles was 0.03 or more, the vehicle would stabilize. Conversely, whenever the coefficient was less than 0.03, the oscillations would continue. For this reason, in all of the analysis work that was done, a damping coefficient of 0.03 for the first two cycles was used as the criterion for stability. A sample output, illustrating stable behavior, is showm in Figure 7.

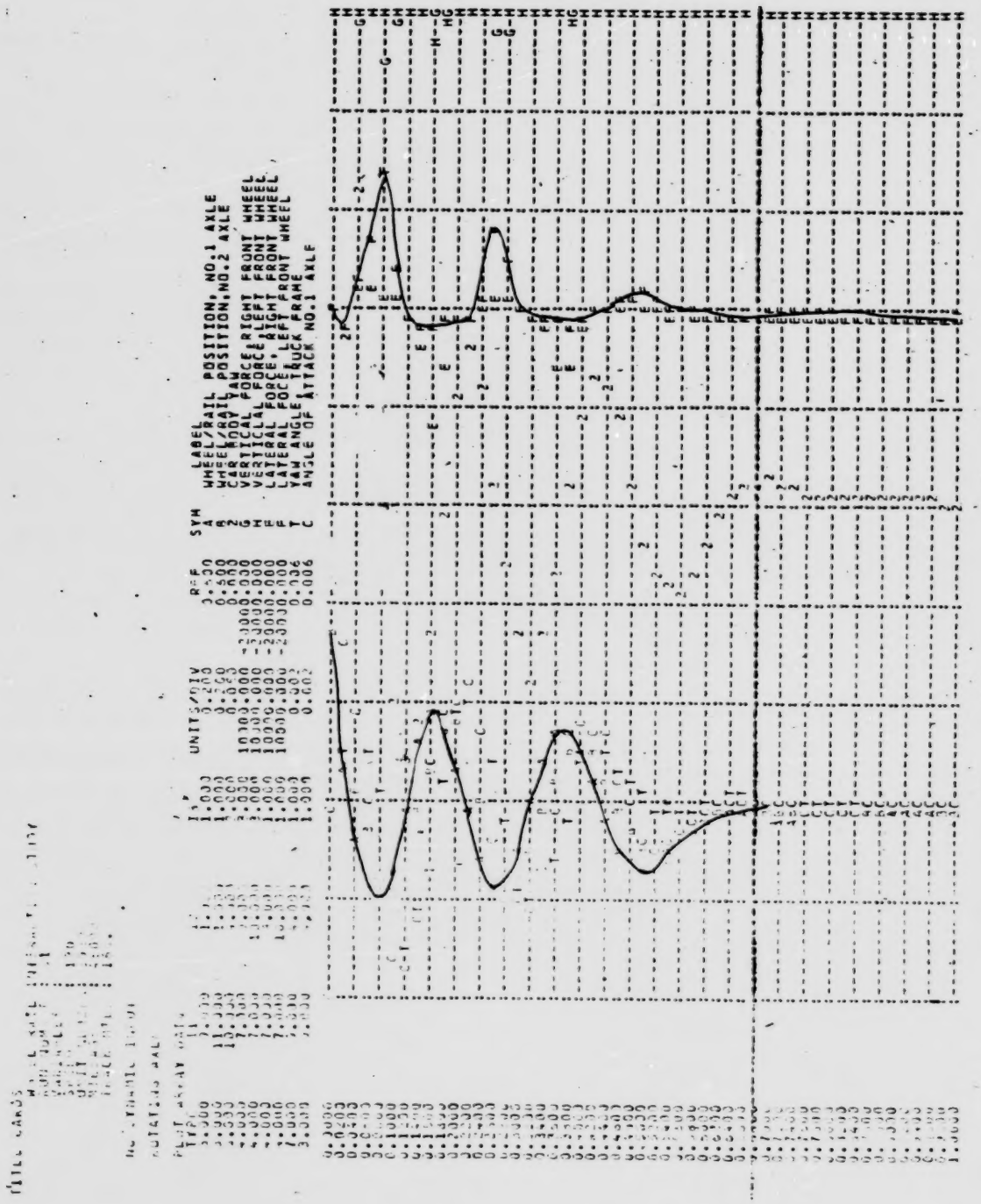

LABEL
WHEEL/RAIL POSITION, NO.1 AXLE
WHEEL/RAIL POSITION, NO.2 AXLE
CAR BODY YAW
VERTICAL FORCE, RIGHT FRONT WHEEL
VERTICAL FORCE, LEFT FRONT WHEEL
LATERAL FORCE, RIGHT FRONT WHEEL
LATERAL FORCE, LEFT FRONT WHEEL
YAW ANGLE, TRUCK FRAME
ANGLE OF ATTACK NO.1 AXLE

Figure 7 Sample Output - DYNSIM Computer Model

4.2.2 Simulation of Test Cases

In order to have confidence in the model, it was necessary that it could accurately reproduce the known dynamic behavior of the LRC locomotive trucks. In Section 3.2, the field data that was used for this validation exercise was described. The model was initially run as received from Railway Engineering Associates, with full Kalker creep coefficients and 33% of the actual contact angles. This latter is on the recommendation of the model's developer, Mr. H.A.List, to compensate for the lack of spin creep in the model. (Spin creep is destabilizing and high contact angles are stabilzing.) The validation exercise results are tabled as follows;

Results of Test Case Simulation Runs

Locomotive	Suspension	Performance Change	Critical Hunting Speed mph	
			Field	Computed
6925	"1983" *	stable (MP 77.5 conicity)	95+	110
	"1983" *	conditionlly stable (MP 165.56 conicity)	95	100
6930	Koni Yaw Dampers	unstable - front truck (MP 165.56 conicity)	95	97
	Koni Yaw Dampers	stable - rear truck (MP 165.56 conicity)	95+	102
	Koni's & New Chevrons	stable - front truck (MP 165.56 conicity)	95+	120

* = the suspension configuration after the initial modification program in 1983. The principal changes applied at that time were new vertical primary suspension dampers and increased rate settings on the friction yaw snubbers (see Appendix V).

Details of all of the suspension configurations are given in Appendix V.

Where the field speed is shown as 95+ it represents situations where the vehicle was stable at the maximun test speed. It is not known what the margin of stability was at these speeds.

When the model showed the trucks to be unstable, the hunting frequency was 5 Hertz at the onset of instability. This agrees exactly with the field measurements for hunting in the 85 mph (137 km/h) to 95 mph (153 km/h) speed range.

Because of the good correlation between the field results and the simulated results shown above, it was decided to use the program as it was initially set up. The principal intent of the modelling work was to evaluate the sensitivity of stability to parameter variation, and it was felt that this could be done with a good degree of confidence.

4.3 Simulation of LRC Locomotive Stability in its Present and Modified Configurations.

The results of all of the stability analysis runs are given graphically in Section 4.5. The critical speeds that apply to the various actual combinations of suspensions and conicities are given below;

	Suspension Configuration	Critical Hunting Speed	
		Average Case Conicity mph	Worst Case Conicity mph
1.	"1983 Suspension"	100	87
2.	"1983 + Koni Yaw Dampers"	112	102
3.	"1983 + Koni Yaw Dampers + New Chevrons"	132	121

The results tabled above indicate that there is now a good margin of stability in the suspension that includes the Koni yaw dampers and the new chevrons. (Note: The new Koni yaw dampers and the new chevrons are being retrofitted to the fleet of LRC locomotives.)

4.4 Simulation of Conicity Change with Wear

The change in conicity with wear for Unit 6925 is described in Section 3.4. The fundamental mechanism of the change from two point contact to full conformity between the wheel and the rail is described. It is proposed by the author in Section 3.4 that, the wheelset may pass through a transitional phase, on its way to becoming fully conformal, that gives higher values of effective conicity in the running zone than the fully conformal profile. The ridge that is developed is not universal, is not uniform in size or lateral location, and does not show up in an identifiable form in the averaged wheelset conicity data. As a

purely theoretical exercise, three sets of effective conicity data were developed, based upon the field data for Unit 6925 at MP 77.5. They apply to the unit at zero mileage, 50,000 miles (80,000 km) with an typical ridge modelled, and to a narrow flange version of the 50,000 mile (80,000 km) profile. The "1983 Suspension" has been used in the calculations. The critical speeds for instability for each of these was determined, and is tabled below;

Conicity Data	Critical Speed
6925(0) - WF	120
6925(50K) - WF	93
6925(50K) - NF	150 +

The results of this exercise are purely theoretical and are not ment to be taken too seriously. They do however, indicate the potentially destabilizing effect of the ridge formation, and the potentially stabilizing effect of the narrow flange profile. Whether large increases in the critical speed could be obtained by using a narrow flange wheel or not would depend on how the actual wheel wear patterns developed in service.

It is not proposed that the stability of the vehicles could be improved by the use of a more conformal profile, that would prevent the transitional formation of this ridge in the wheel profile.

4.5 Sensitivity of Stability to Parameter Variation

4.5.1 Effective Conicity (Field Data)

The sensitivity of the "1983 Suspension" to the averaged field conicity values is shown in Figure 9. The critical speeds are tabled below;

Conicity Data	Critical Speed
Worst Case	87
Average Case	102
Best Case	112

It was consistently observed in the field that hunting was not continuous, but was site sensitive. These results, showing a variation of 25 mph in the critical speed, depending on the track and wheel profile conditions, show how this can occur.

4.5.2 Effective Conicity (Theoretical)

A set of theoretical values of effective conicity was developed for this exercise. Figure 9 shows the rolling radius and contact angle difference data that was used, and the stability plot for the results. It is seen that the critical hunting speed continues to fall with increasing conicity, although the rate is less than linear. The fully modified suspension was used for this exercise.

4.5.3 Flangeway Clearance

Wide gauge is known to be stabilizing, and tight gauge to be destabilizing. The effects of 1/8 inch (3 mm) tight gauge was modelled using the fully modified suspension and a nominal value of 0.3 effective conicity. The results indicate that the critical hunting speed is reduced from 135 mph (217 km/h) to 127 mph (205 km/h) by the tight gauge. Tight gauge of this order of magnitude was found at at least one location in the field on mainline track during the LRC locomotive stability testing that was done in 1983.

4.5.4 Primary Suspension Longitudinal Stiffness

The sensitivity of the vehicle stability to the primary suspension longitudinal stiffness is shown in Figure 10. The worst case conicity data was used and the stiffness was varied between 62,000 lbs/in/journal (10.86 kN/mm/journal), and 130,000 lbs/in/journal (22.77 kN/mm/journal). The rate for the "1983 Suspension" is 62,000 lbs/in/journal (10.86 kN/mm/journal), and the rate with the new chevrons that are being used in the fleet retrofit is 100,000 lbs/in/journal (17.51 kN/mm/journal). It is seen that the stability was still increasing with increasing stiffness at 130,000 lbs/in, (22.77 kN/mm) but at a less than linear rate.

4.5.5 Primary Suspension Lateral Stiffness

The primary suspension lateral stiffness is nominally 33,000 lbs/in/axle (5.78 kN/mm/axle). The model was run using this value, and at 48,000 lbs/in/axle (8.41 kN/mm/axle) and 66,000 lbs/in/axle (11.56 kN/mm/axle), with the worst conicity, and with the longitudinl suspension at its nominal setting of 62,000 lbs/in/journal (10.86 kN/mm/axle). There was no appreciable change in the critical speed of hunting. The results are not shown. It is concluded that the vehicle stability is relatively insensitive to lateral stiffness variation from its existing level.

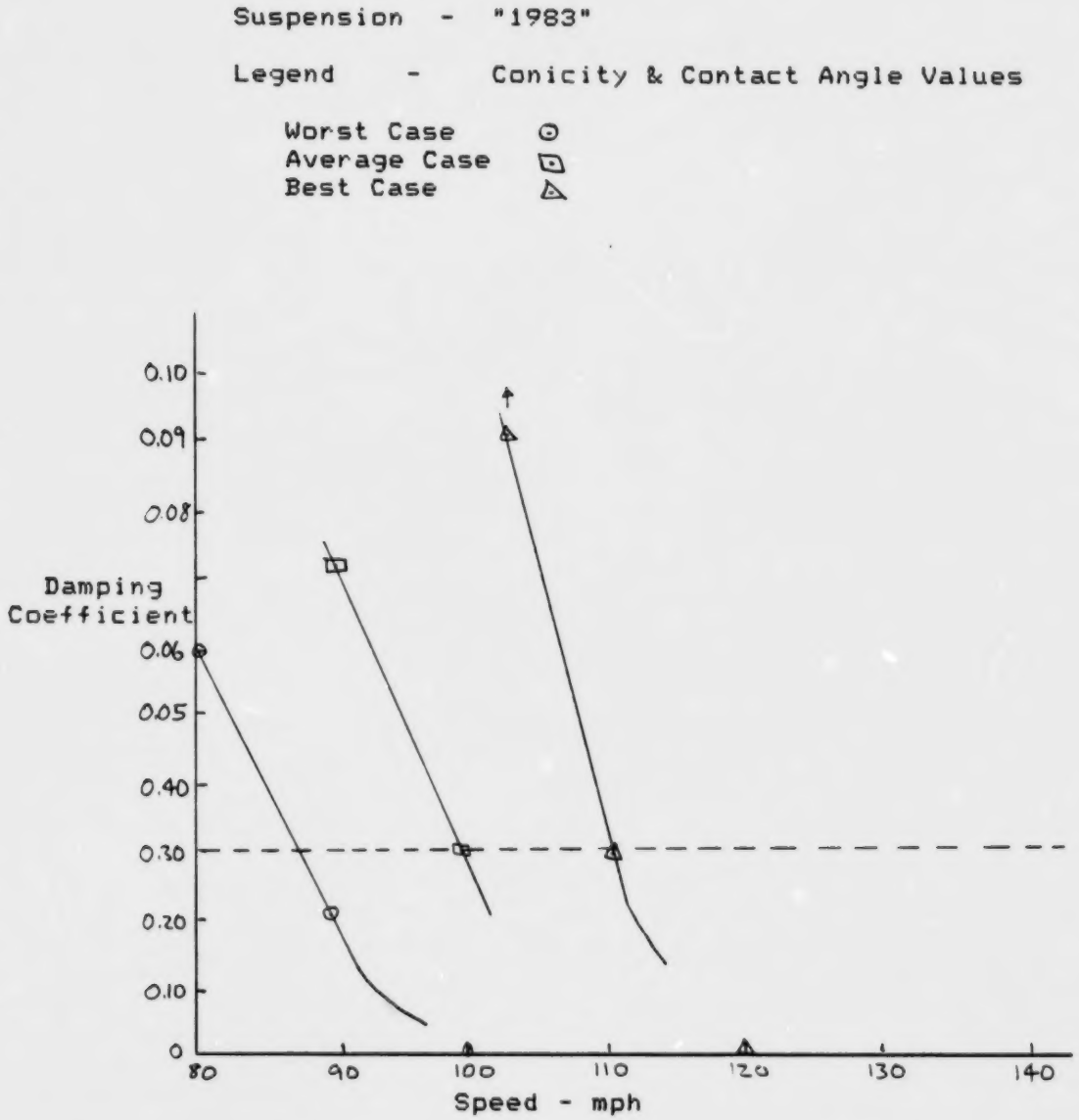


Figure 8 Sensitivity of Stability to Field Effective Conicity and Contact Angle Difference

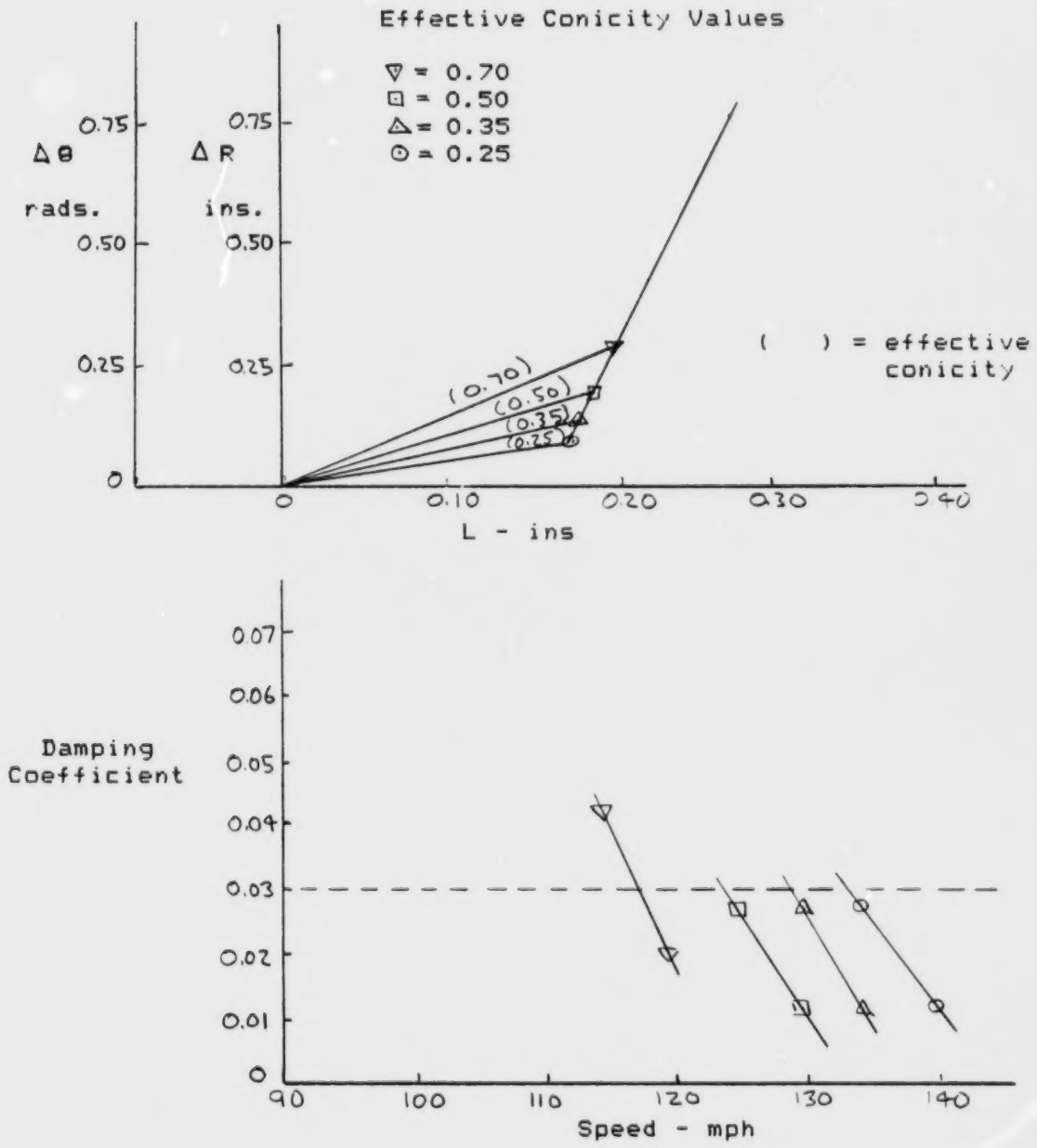


Figure 9 Sensitivity of Stability to Nominal Effective Conicity and Contact Angle Difference

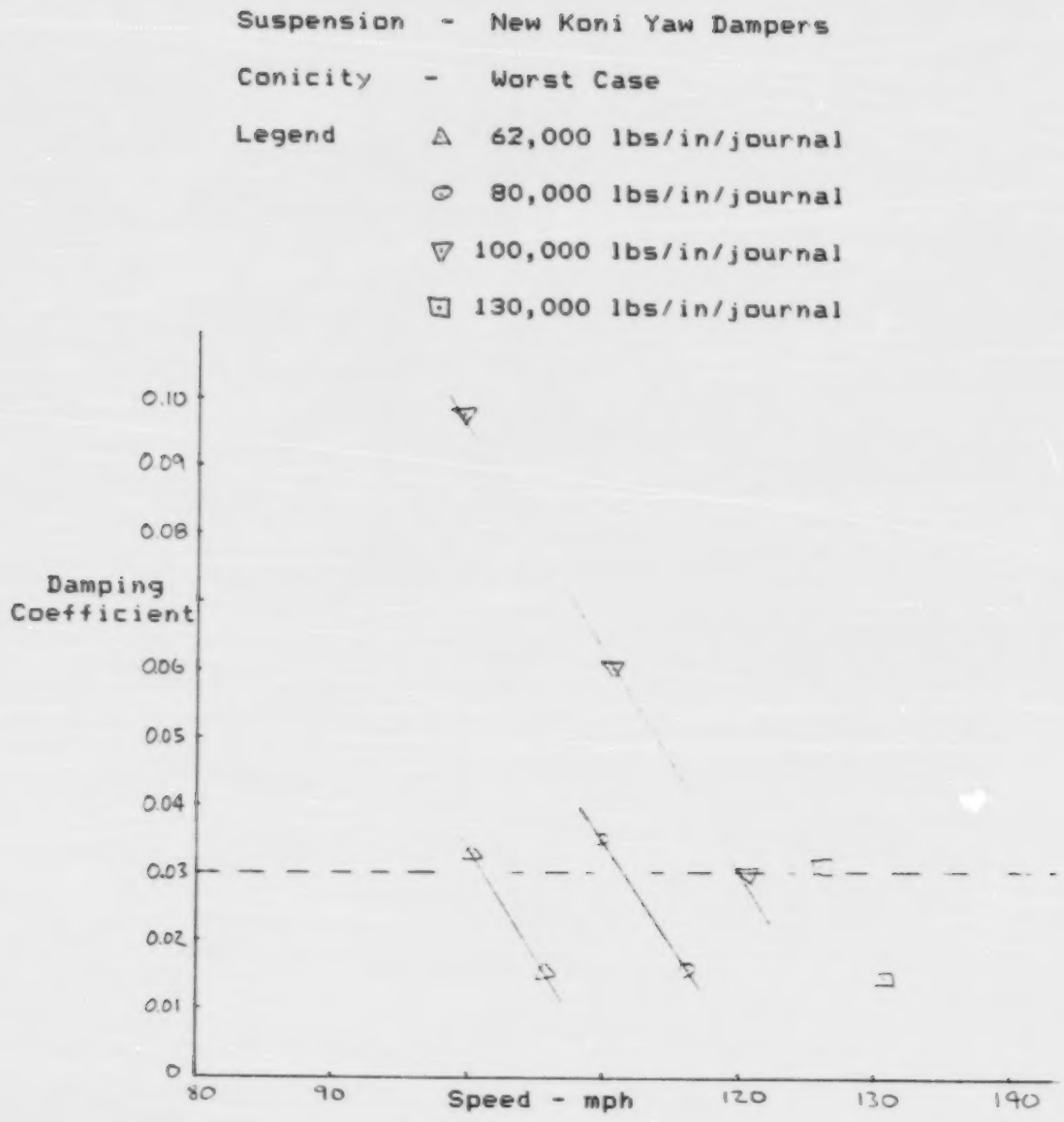


Figure 10 Sensitivity of Stability to Primary Suspension Longitudinal Stiffness

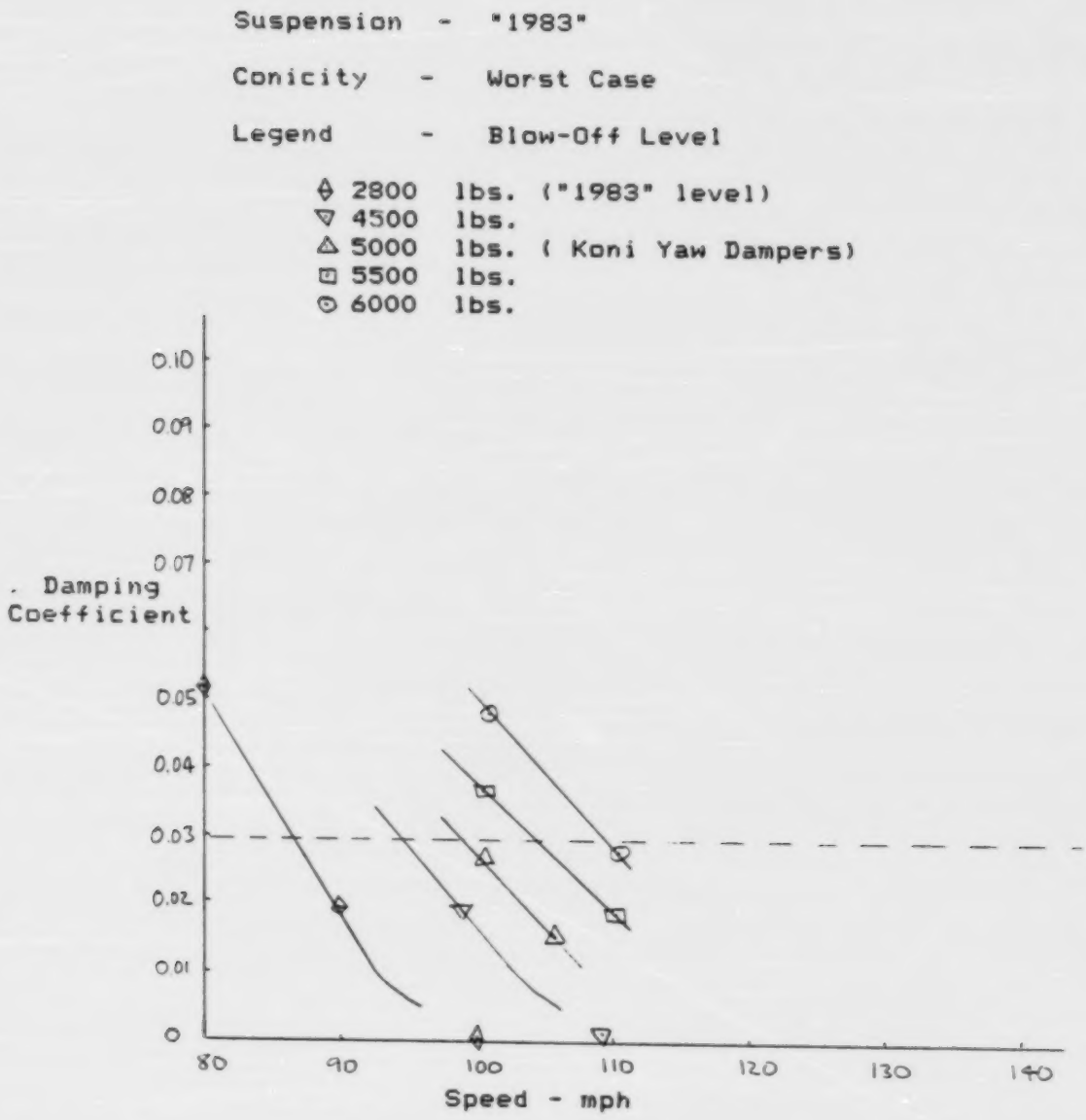
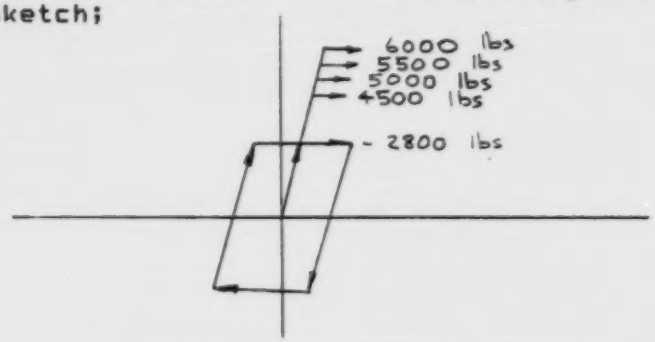


Figure 11 Sensitivity of Stability to Secondary Suspension Yaw Damping

4.5.6 Secondary Suspension Yaw Damping

The sensitivity of the vehicle stability to secondary suspension yaw damping is shown in Figure 11. The damper is a "yaw relaxation damper", which is best represented, at the higher angular rotational velocities associated with hunting, as a very stiff spring in series with a friction slider with a given breakaway level. The spring represents the stiffness of the bushings, bracketry assembly, and hydraulic column of the damper. It is taken to be 200,000 lbs/in (35.03 kN/mm), based on actual test results. The friction slider is represented by the "blow-off" level on the hydraulic damper. Force vs. distance for the device is shown diagramatically in the following sketch;



This shape is modelled in the DYNSIM computer program and is an accurate representation of the actual operation of the damper at 5 Hz. The 2800 lb. (12.46 kN) blow-off level represents the old friction snubber on the "1983 Suspension". The replacement Koni yaw damper has a blow-off level of between 5000 lbs. (22.24 kN) and 5500 lbs. (24.47 kN). It is seen that the critical hunting speed is increasing linearily with increasing blow-off level, over the range studied, with no signs of saturation.

4.5.7 Directionality

When Unit 6930 began to hunt again, the unit was in the trailing position, and the cab end truck was hunting. The other truck was stable. This meant that the only truck that was hunting was the last one in the train consist. This raised questions about the possible effects of direction on stability. It was not possible at the time to test the unit in the leading position. The average conicities for the wheelsets of the lead and trailing trucks were sufficiently different to allow approximately five mph difference in the calculated critical hunting speeds (see Sect. 4.2.2). This could explain the difference in performance between the two trucks.

The question as to whether directionality has an effect on stability remains unresolved.

4.5.8 Track Cant Angle

The effect of small variations in cant angle was studied. The CN Research Final Report includes change in rolling radius plots for wheelset #1, Unit 6925 (50,000 miles), at MP 77.5, with +/- 0.5 degrees of cant angle rotation about a nominal 1/40 value (see Figures LRC # 36 & 37, CN Research Final Report). This same data was also available for the actual rail condition (Figure LRC # 5, CN Research Final Report). The nominal 1/40 cant gives an angle of 1.43 degrees. The effective conicity data was plotted, and showed that the effect of the angular rotation is to change the apparent flangeway clearance, even at nominal standard gauge. To increase the angle by .5 degrees is equivalent to increasing the flangeway clearance by 1/16 inch. This will be stabilizing. The reverse effect is apparent when the angle is reduced.

4.6 Consideration of Other Wheel Profiles

One of the conclusions of this study is that the instability onset after several months of service is due to a wearing in process whereby the wheel goes from two point contact to being fully conformal. There may even be a transition period when the conicities are more destabilizing than they would be when the profiles are fully conformal. However, it does not logically follow that an improved profile design is required. The CN Modified Heumann profile gives single point contact on 115 lb. RE rail, and two point contact on 132 lb. RE rail. It is, however, very close to single point contact on the 132 lb. rail. The CN Research Profile "A" has also been examined, and gives close to conformal, two point contact, on both the 115 lb. and the 132 lb. rail. It is the opinion of the author that stability cannot be improved by slight modifications to the "as new" profile design. It has also not been clearly established that the transition period from two point to conformal is more destabilizing than the established fully conformal state.

It is likely, however, that the stability could be substantially improved by going to a narrow flange (NF) wheel. Use of the narrow flange wheel increases the nominal flangeway clearance between the wheel and the rail from 0.313 ins. (8 mm) per side, to 0.469 ins. (12 mm) per side. Any potentially destabilizing wear effects in the flange root area would, therefore, be far enough out of the running zone affecting high speed stability that their effects on stability would be greatly reduced. This conclusion is purely theoretical. The modelling shows that increasing the flangeway clearance is very stabilizing, but no actual information concerning the stability performance or the wheel wear patterns for the LRC locomotive with a conformal, NF, wheel profile exists.

5.0 Conclusions

5.1 DYNSIM Model Accuracy

It has been shown that the DYNSIM non-linear computer model accurately predicted the speeds of onset of instability in the test cases (see Section 4.2.2), in its "as received" condition from the author, Mr. H.A. List, Railway Engineering Associates. The model has been primarily used in this study to examine the relative effects on critical speed of parameter variation, taking as baseline the known performance of existing hardware. There is reason to have a good level of confidence in the results obtained using the model in this way.

5.2 Field Effective Conicity Measurements

The effective conicity data is discussed in detail in Section 3.5. The principal conclusions are as follows;

i) effective conicity values of 0.69 in the running zone were calculated with Unit 6930 at MP 165.56. There is a possibility that some asymmetry was machined into these wheelsets that could have increased the conicity artificially (see Section 3.3).

ii) effective conicities of 0.50 were encountered at the same track section with Unit 6925. The wheel profiles of this locomotive were not suspect.

iii) the nominal conicity, for the new CN Modified Heumann wheel profile on 132 lb. RE rail, over the same running band as i) and ii) above, is 0.40.

iv) the best worn wheel conicities found were 0.07, at MP 77.5. These low values are more the result of the rail profile than the wheel profile (see Section 3.5).

It has also been shown that the critical hunting speed is sensitive to changes in conicity (see Figure 9). This wide range of effective conicities must be taken into consideration by the vehicle designer, to insure stable operation at the design speeds.

5.3 Destabilizing Effect of Wheel Wear

A mechanism for the destabilizing effects of relatively modest wheel wear ((20,000 to 40,000 miles) (32,000 to 64,000 km)) on the stability of the LRC locomotive using the CN Modified Heuman wheel profile, is proposed (see Sect.3.4). It is shown that the transformation from two point contact to full conformity increases the effective conicity. It is also proposed that there may be a transition phase that the wheelset goes through in becoming conformal, which gives higher conicities than the fully conformal profile.

5.4 Effect of LRC Locomotive Suspension Modifications

The fleet of LRC locomotives is, at time of writing, being retrofitted with new Koni yaw dampers and the longitudinally stiffer chevrons. According to the sensitivity analysis that has been conducted using the DYNSIM model the locomotive will be stable to 121 mph (195 km/hr), using the worst case conicity data. It is noted that the wheel profile used in developing this data is suspect, because of the possibility of an error in the template used in machining a simulated 30,000 mile (48,000 km) profile on these wheelsets (see Section 2.2). The modified locomotive corresponds to the 100,000 lb/in/journal curve of Figure 10.

The critical hunting speed for this locomotive configuration using the average conicity values has been calculated to be 132 mph (213 km/h). The corresponding speed for the nominal conicity (see CN Research Final Report, Figure LRC # 34) is 133 mph (215 km/h).

These results indicate that there is a good margin of stability in the modified suspension arrangement. It is expected that the locomotives will remain stable in 95 mph (153 km/h) revenue service, using the CN Modified Heumann profile, until the normal condemning wear limits are reached. It should be noted, however, that the maximun mileage for which wheel profile data is available is 66,000 miles (106,000 km). Until the wear patterns are established for the higher mileages, it will not be possible to predict the continued on-going stability of the vehicles with certainity.

5.5 LRC Locomotive Wheel Profiles

It is not recommended that a wheel profile change, from the CN Modified Heumann, be made. Any wide flange profile that is used will eventually wear to a very similar shape to that of the fully worn-in CN Modified Heumann. There is also reason to expect that the modified vehicles will remain stable until the normal condemning wear limits are reached, using the CN Modified Heumann profile. Via should now be able to begin to take

advantage of the increased wheel life potential of a conformal type, wide flange, profile.

It should, however, be noted that a narrow flange (NF) wheel does have the potential of further improving the stability by providing a wider running band before the flange root area is reached. It is not recommended here because it is unknown and not required. It could be considered for future higher speed operation, or for other truck designs.

5.6 Implications for Higher Speed Operation

If there was a future requirement to increase the running speed of these locomotives, and a higher critical hunting speed was required, the following steps could be taken;

i) the wheel profiles could be controlled through more frequent machinings, as is presently done on many high speed rail vehicles.

ii) a conformal type, narrow flange, profile could be used. This would entail a period of stability monitoring and profile measurement.

iii) the suspension could be further improved.The sensitivity studies indicate that neither the yaw damping or the primary suspension longitudinal rate are fully optimized. It should be noted, however, that it may not be possible to obtain the physical hardware with the necessary properties to do this, while at the same time continuing to fulfil the other functions of the suspension. For example, it may not be possible to further increase the longitudinal stiffness of the primary suspension without increasing its vertical stiffness. Increasing the vertical stiffness has a negative effect on wheel unloading. As a second example, further increasing the yaw damping could have a negative effect on curving.

5.7 Apparent Rail Geometry Anomalies

It has been observed throughout the LRC locomotive testing program over the last four years, that new rail has a destabilizing effect on stability. The rail profile measurements at MP 165.56, where the rail had only been in service for four to five months, and where hunting of test unit 6930 was observed, indicated both high conicity and an offset of the zero rolling radius position. The shiny patch observed in October, 1985, indicated that the vehicles were not running in the center of the rail. A second visit was paid to the site in October, 1986, to see if there were any signs of asymmetry between the rail head and base that could be attributed to a

manufacturing error. No signs of asymmetry were found. It was observed that the running band on the rail head seemed to be normally centered again.

The cause of the high conicity and zero offset at this site has not been determined. It can only be concluded at this point that there is nothing out of specification about the track and that the conicity values obtained are values that the vehicle designer has to consider in his stability calculations.

5.8 Track Measurement under Load

The possibility of measuring the track movement under load has been discussed at several meetings of the review committee for this project. Depending on the form of the lateral motion, it could have either a positive or negative effect on the vehicle stability. It is not recommended by the author at the present time, however, because of the good correlation between the calculated and the actual results, using the unloaded rail measurements. This could be considered at a later date if unexplained instability problems arise with the LRC locomotives.

6.0 Proposals for Further Development Work

6.1 LRC Locomotives

It is proposed that, as the suspension modification are completed, the LRC locomotives should have their wheelsets machined to the CN Modified Heumann profile, and be allowed to run in unrestricted revenue service. A monitoring program should be set up where once a month, a simple stability road test (one accelerometer per truck) would be conducted. The locomotive should be selected based on its wheelset mileages since reprofiling. Wheel sets should be measured periodically, using the simple pencil profile tracing device, to keep track of the changes in shape with wear, beyond 50,000 miles.

In the event that hunting recommences, arrangements should be made to have the CN Research team measure the wheel profiles on the hunting vehicles, and the rail profiles at the hunting site, using the digital recording equipment used in this project, so that the effective conicity data can be developed.

When a LRC locomotive has reached a normal wear limit using the AAR condemning criteria, a high speed test should be conducted to establish the margin of stability at this point.

6.2 Vehicle Stability Modelling

Because of the good correlation between the model results and actual field conditions, it is recommended that a comparison be made between these results and results obtained using the linear stability models that are in more common useage in the industry.

6.3 Rail Anomalies

It has still not been resolved why the newly laid rail at MP 165.56 was destabilizing. This matter is probably not of importance to the LRC locomotives, whose suspensions are now capable of running over this and similar rail with a good margin of stability. It may, however, be of broader general interest to the railway industry, where hunting of other types of vehicles is still a problem. It is recommended that follow up work in this area be considered.

APPENDIX I

Project Chronological History

APPENDIX I

Project Chronological History

A brief chronological history of the project is presented below:

1985

February	Contract start date (February 8).
March	S.P.E.C. planning session held at CP Rail (March 19).
August	Test Unit 6925 assigned to the program by Via Rail. Unit equipped with standard suspension and CN Modified Heumann wheel profile.
	Wheel profiles measured by CN Research at Via Rail, Ville St. Pierre Shops, at zero mileage. Unit released to revenue service (August 8).
	First monitoring test conducted, unit stable (August 27).
	Unit 6930 monitored and one truck found to be hunting after 46,000 miles (74,000 km) of service with new Koni yaw dampers (August 22).
September	Unit 6930 inspected and tested to determine cause of instability. Pre-load found to be within allowable limits but low, on hunting truck. Preload increased, unit retested, unit still hunting (September 22).
	Pencil trace wheel profile measurements of 6930 taken.
	Unit 6930 equipped with new primary suspension chevrons with stiffer longitudinal rate.
	Units 6925 & 6930 tested to 103 mph (166 km/h) in non-revenue test. 6930 stable under all test conditions. 6925 showed several bursts of marginal instability at 103 mph (166 km/h) (September 29).

October	Track geometry measurements taken at MP 165.56, Kingston Subdivision, CN Rail, by CN Research (October 28). Site selected because unstable operation had been found there.
November	Unit 6925 monitored for stablity - stable.
December	Unit 6930 had wheel profiles measured by CN Research, at Via Rail, Ville St. Pierre Shops, at 66,000 miles (106,000 km) (December 6).
	Track geometry measurements taken at MP 77,5, Kingston Subdivision, CN Rail, by CN Research (December 10). Site selected as typical of stable operation.
	Unit 6925 monitored for stability. Signs of instability found after 40,000 miles (64,000 km) wear. Via advised safe to leave the unit in service over the Christmas rush period (December 18).
1986	
January	Wheel profiles measured on Unit 6925 at Bombardier by CN Research, at 50,000 miles (80,000 km) (January 20). Unit returned to revenue service with 1:40 WF wheel profile.
	Interim Report # 1,"LRC Primary Suspension Modification Test", submitted.
February	Wheels of Unit 6930 machined to conventional profile in error (February 21). End of test program.
February - June	DYNSIM computer program commissioned.
	Interim Report # 2, "Literature Review Report", submitted.
	Field data processed by CN Research and reviewed with Bombardier.
July	CN Research Final Report received.

September	Interim Report # 3,"Wheel and Rail Profile Measurements and Effective Conicity and Contact Angle Development", submitted.
	Theoretical analysis portion of program completed.
	Steering committee meeting held (September 29).
October	Track inspection (October 15)
	Final Draft Report submitted (October 19).
December	Final Report Submitted

APPENDIX II

Interim Report #1

LRC Primary Suspension Modification Test

September 29, 1985

PROJECT NO.
439300

REPORT NO.
1

Bombardier Inc.

Rail and Diesel Power Products Division

MONTREAL CANADA

TRANSPORTATION ENGINEERING

DEVELOPMENT SECTION

SUBJECT TDC Wheel/Rail Interaction Program
Contract No. OSD84-00277

Interim Report No. 1.

LRC Primary Suspension Modification Test
Sept. 29, 1985.

COMPILED BY: David D. Taylor, P. Eng.
David D. Taylor & Associates Inc.

APPROVED BY: R. S. Bergner

DISTRIBUTION

SUMMARY

FULL REPORT

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Appendix	Title
1	List of Hunting Criteria
2	Koni Yaw Damper Test Results
3	Test Instrumentation
4	Wheel Profiles

LRC Primary Suspension Modification Test

1.0 Introduction

The TDC Wheel/Rail Interaction Program was designed to complement the LRC locomotive truck development program that was active between August, 1982, and September 1985. It was intended to do this in two ways, to maximize the learning potential of the development program, and to establish the requirements for future, higher speed operation of the LRC locomotives.

The LRC locomotives supplied to Via Rail in 1982 used CN Modified Heumann wheel profiles. The prototype LRC used the AAR 1:20 NF profile, and the Amtrak LRC's used an AAR, 1:40, NF, profile. Both profiles are included in Appendix 4. Using the Heumann profile, the locomotive developed unstable truck hunting oscillations after ten to twenty thousand miles of service. Mathematical analysis that was done at this time indicated that the stability could be improved through the following modifications:

i) improved secondary yaw damping. (+25 to +30 mph)

ii) increasing primary suspension lateral and longitudinal stiffness. (+15 to +20 mph)

iii) use of a narrow flange (NF) profile instead of a wide flange (WF) profile. (+30 mph) (both CN Modified Heumann).

The decision was taken at that time to attempt to resolve the stability problem through the use of improved yaw damping alone. Dofasco obtained one locomotive set of primary suspension chevrons with increased longitudinal and lateral rates, as a back-up, in case the improved yaw dampers were not, in themselves, sufficient to resolve the stability problem. Independent evaluation of the effect of these chevrons on truck stability was one of the goals of the TDC program. It was, however, understood that these chevrons would be tested with the new yaw damper, if the requirement arose. Units 6923 and 6930 were equipped with the new yaw dampers and run in revenue service with the Heumann profile. All other units were equipped with the AAR, 1:40, WF, profile. This profile was returned every 50,000 miles.

Both units were periodically monitored for stability in revenue service. On August 22, 1985, the leading truck on Unit 6930 was unexpectedly found to be hunting.

The hunting occurred over a specific section of track, MP 162-170, Kingston Subdivision, CN Rail. The locomotive trucks were closely inspected for abnormalities that could explain the instability, but none were found (see Sect. 2.3). The new chevrons were, therefore, installed on 6930 instead of 6925, and tested, together with the improved yaw dampers, on Sept. 29, 1985.

The description of this test constitutes the body of this report.

2.0 Background

2.1 Unit 6930 Instability.

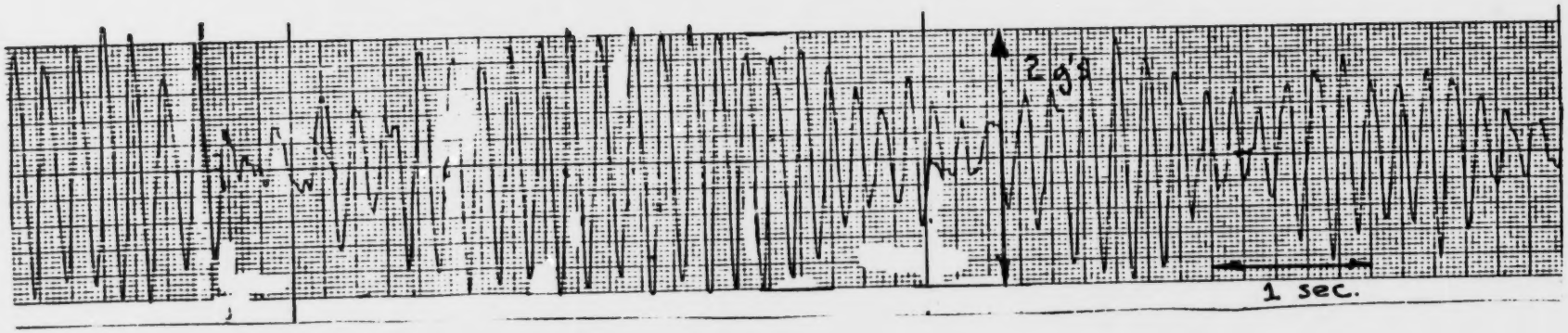
The front truck of Unit 6930 was established to be hunting in revenue service on Aug. 23, 1985. The locomotive was in the trailing position in the consist, so that it was actually the last truck in the train. The unit had approximately 45,000 miles of service on its wheelsets. The instability was encountered between MP 162 and MP 170, Kingston Subdivision, CN Rail, at the maximum line speeds of 95 mph.

A typical sample of the hunting is shown in Fig. 1.

A definition of hunting was established during the LRC truck development program, and is included in Appendix 1. By this criterion, the activity is in the upper range of the "grey" area. However, there is no reasonable doubt that the truck was hunting.

2.2 Special Wheel Profile, Unit 6930.

The LRC locomotive fleet is presently running on AAR 1:40 wheel profiles. They are being remachined every 50,000' miles, in order to maintain the profile shape. The two principal test locomotives, 6923 and 6930, were using the CN Modified Heumann profile specified by the contract. Milestone tests were to be conducted when the units reached 50,000 miles service. Both units were approaching this total in May and June, 1985, when their wheels had to be machined because of thermal cracks. This would have delayed the program by a year, as it takes six months to accumulate the mileage, and stability tests cannot be performed in the winter. To resolve this problem, a special template was designed and built by Bombardier to simulate 30,000 miles of wheel wear.



Unit 6930 - Axle No. 1
- Locomotive Trailing
- MP 166.5, North Track
- Speed 95 mph
- Dry Rail
- Filtration 10 Hz

Fig. 1 Hunting Sample, Aug. 22, 1985.

The template was based upon wheel profile traces taken on Unit 6923 at approximately 30,000 miles. The procedure was checked in detail by Bombardier, CN Rail and Via Rail in July, 1985, and the wheelsets of both units were machined by CN in late July. The 45,000 miles stated for unit 6930 is comprised of 15,000 miles of running on the 30,000 mile simulated profile.

This is a useful technique for simulating worn wheelsets for testing purposes.

2.3 Suspension Test and Inspection

Once it had been established that unit 6930 was hunting, it was immediately removed from service. The following steps were taken to identify any abnormality that could explain the vehicle instability:

i) A visual inspection of both trucks was made. Nothing abnormal was found.

ii) The profiles of all eight wheels were taken using the Bombardier profilometer (Yoshida Seiki Co.Ltd., Type TS-3D). The traces are shown in Fig. 2. They were magnified to four times normal size and compared with the 30,000 mile template (see Sect. 2.2). Again, nothing abnormal was found.

iii) All four secondary yaw dampers were removed and returned to Koni for testing. Three of the four dampers were still within the nominal new tolerance bandwidth. The fourth was only marginally outside these limits. The decision was taken to re-install the dampers exactly as tested. The basis for this was that if the truck performance was so sensitive to damper performance that tuning the dampers back up to 100% rating cured the instability, the dampers did not represent a realiable solution to the problem.

The Koni test report is attached as Appendix 2.

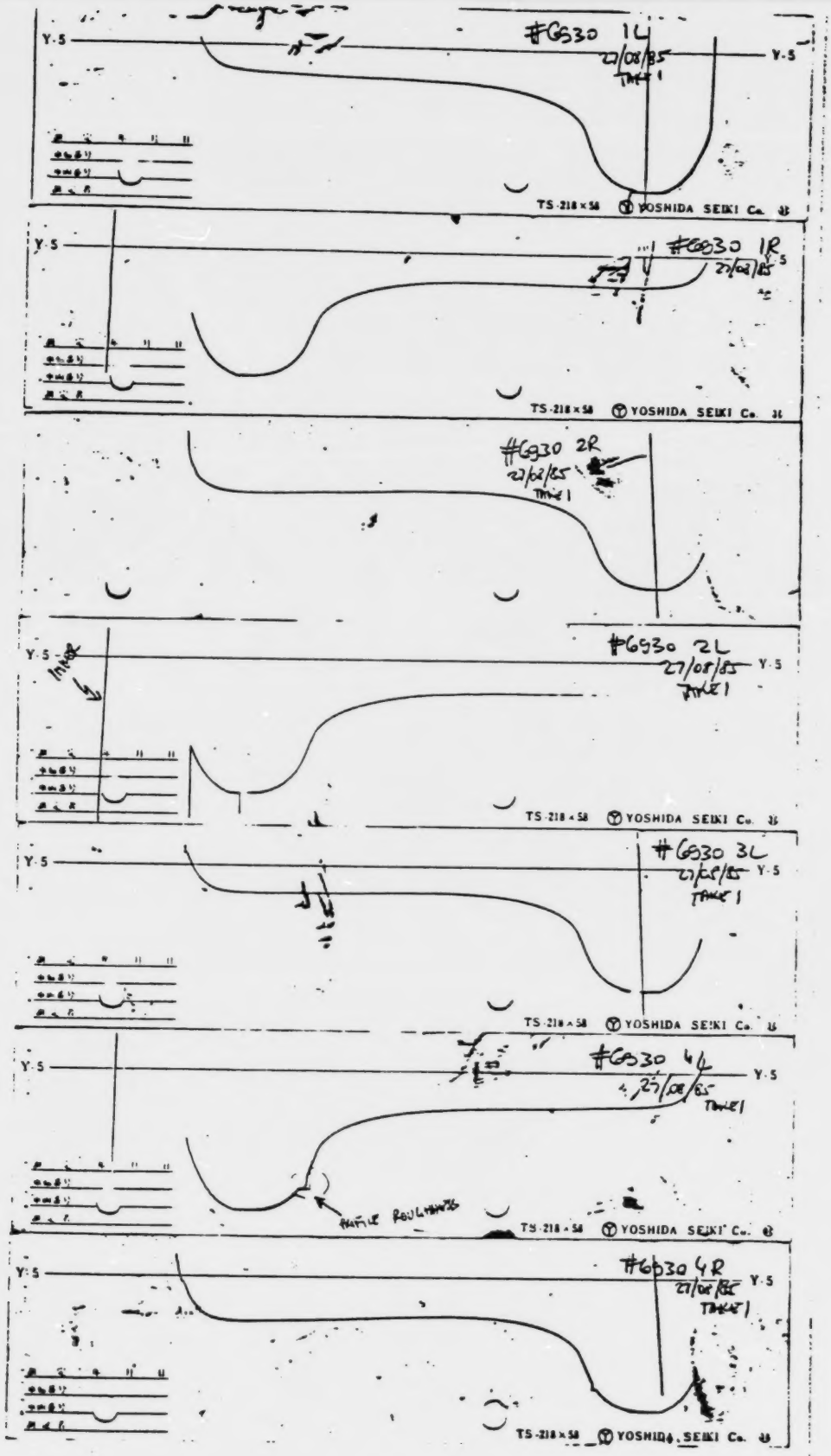


Fig. 2 - Wheel Profiles, Unit 6930
August 27, 1985.

LRC Locomotive 6930 Preload Test

Pedestal No.	Preload (lb) Load Cell Method	Preload (lb) Jacking Method	Average Preload (lb)
1L	3,400	11,500	7,450
1R	4,500	10,400	7,450
2L	2,200	11,200	6,700
2R	2,400	12,700	7,550
3L	5,400	12,800	9,100
3R	5,500	10,400	7,950
4L	6,800	10,800	8,800
4R	6,100	11,000	8,550

Test Date: Sept. 6, 1985.

TABLE 1

iv) The preloads on the primary suspension chevrons were checked by Dofasco on Sept. 6, 1985. The preload is important in this suspension design because loss of preload with longitudinal motion of the axle box effectively halves the longitudinal rate of the suspension. If this was happening, it could certainly explain the occurrence of hunting. The measurement techniques used are, by their nature, prone to error, but the results of one method did show that the average preload on the front, or hunting, truck was approximately half of that on the trailing truck. It was still theoretically high enough to prevent unloading, but the decision was taken to insert 1/4" shims between the outer chevrons and the truck frame. This would eliminate any possibility of suspension unloading. This was done, and the locomotive was retested on Sept. 22, 1985. The results are illustrated in Table 1.

2.4 Retesting of Unit 6930.

Unit 6930 was retested, with the front truck primary suspension shimmed, on Sept. 22, 1985. To the greatest extent possible, the conditions of August 22 were duplicated. The unit was in the trailing position, and on the same (north) track. The weather was dry for both tests. The speeds were the same maximum line speeds of 95 mph. The unit had not been in service in the interim period, so that the wheel profile had not changed. the only uncontrolled variable was the track wear in the intervening month, which would not be significant.

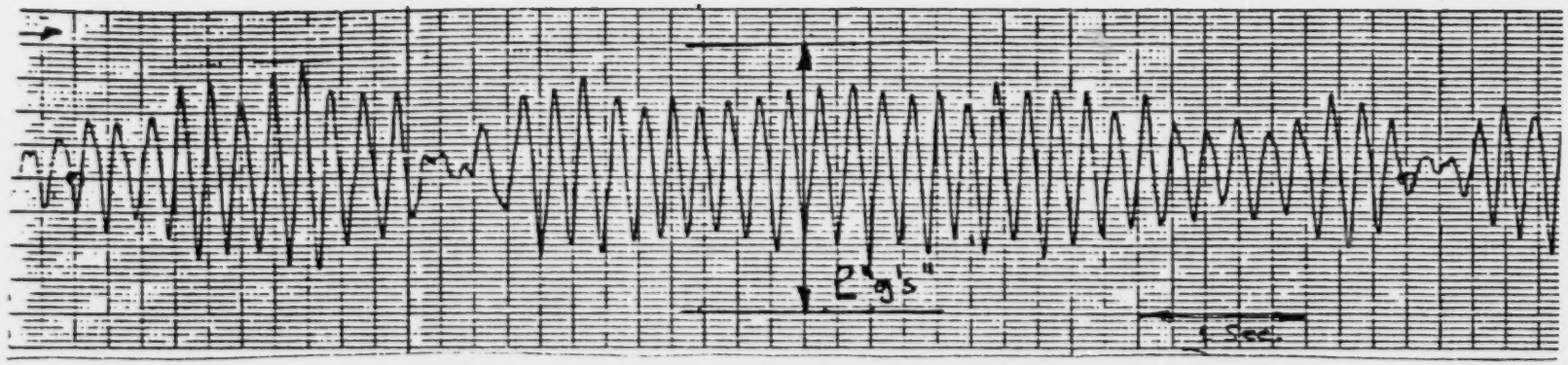
The unit was still hunting between MP 162 and 170, although not as badly. The patterns repeated almost exactly at the same points on the track. Fig. 3 illustrates a typical result for the test of Sept. 22, at the same point in rail as that of Fig. 1. It is seen that the amplitudes are reduced, but that the continuous beating pattern typical of hunting is still present.

2.5 Interim Conclusions.

It was decided, based upon the test results of Sept. 22, that the improved yaw dampers themselves did not represent a solution to the hunting problems. The new chevrons, reserved for the TDC program, would have to be installed on 6930, and tested together with the yaw dampers, during the high speed tests already scheduled for Sept. 29, 1985.

It was essential that the new chevrons increase the longitudinal and lateral rates of the primary suspension without increasing the vertical rates. A modest increase in the vertical rate would have raised the truck pitch natural frequency, excited by the rail joints, closer to the 95 mph maximum operating speed. A larger increase would have raised concern about high wheel unloadings associated with stiff primary vertical suspensions. The rates for the standard and modified suspensions are given in Table 2.

A drop test was also performed to confirm the pitch natural frequency of the truck. Results are described in Sect. 3.6.



Unit 6930 - Axle No. 1
- Locomotive Trailing
- M.P. 166.5, North Track
- Speed 95 mph
- Dry Rail
- Filtration 10 Hz
- 1/4" Shim added to Primary Suspension

Fig. 3 Hunting Sample, Interim Test
Sept. 22, 1985.

Rate	Conventional lbs/in/journal	Unit 6930 lbs/in/journal
Vertical		
- chevron	4,000	5,000 [1,2]
- coil springs	2,823	2,823
- total	6,823	7,823 [3]
Longitudinal	55-60,000 [2]	99,000 [2]
Lateral	30,000	33,000 [2]

Notes: 1. Metalastik 17/1153 16 x 45 Dofasco Dwg. DTC-9467-0.

2. Actual measured rates.

3. See Sect. 2.5

TABLE 2 - LRC Locomotive Primary Suspension Rates.

3.0 High Speed Test - Sept. 29, 1985.

3.1 Test Arrangements.

The tests scheduled for Sept. 29, 1985 were for up to 110 mph. in order to satisfy the requirements of the contract with Via Rail. Because this is in excess of the maximum 95 mph line speed, special arrangements were required. A contract was drawn up and signed between CN Rail and Bombardier, and CN Rail made the necessary arrangements with the Canadian Transportation Commission. Flagmen were required at all level crossings over the test area, and all farmers crossings were chained shut for the test day. The entire track section between MP 69.4 and MP 103.7 was reserved for 110 MPH operation. Arrangements were also made to run at maximum track speeds over the section of track where the hunting had been encountered (MP 162 to MP 170). It was not possible to run at higher speeds over the section.

These arrangements were beyond the scope of the TDC program, and are added here for completeness.

3.2 Condition of Locomotive 6930.

The condition of the trucks on LRC locomotive unit 6930 on the day of testing was as follows:

i) Wheel profile

CN Modified Heumann WF, with 45,000 miles of service on the wheelsets since the last turning. (See Sect. 2.2).

ii) Primary Suspension Chevrons

The standard chevrons were replaced on this unit by experimental chevrons with stiffer longitudinal and lateral rates. (Metalastik 17/1153, 16 x 45, Dofasco Dwg. No. DTC 9467-0, see Table 2).

iii) Secondary Yaw Dampers.

The locomotive was equipped with Koni yaw dampers (Koni No. 04R-1131-001).

iv) Secondary Pitch Dampers

The locomotive was also equipped with relocated secondary vertical dampers. These are the conventional LRC locomotive dampers, but have been relocated from inside the secondary coil springs to the four corners of the truck. This arrangement is part of an independent test program to critically damp the truck pitch, and was not expected to have any effect on the truck's stability performance.

Fig. 4 shows a photograph of the primary suspension of Locomotive 6930, including the new chevrons, the new primary suspension damper, and the relocated secondary vertical damper.

3.3 Instrumentation.

The instrumentation for the test was supplied, installed and monitored by Dofasco. The following parameters were monitored on unit 6930.

i) Truck Hunting

Axle #1 lateral acceleration measured on the truck frame over the journal box.

Axle #2 lateral acceleration measured on the truck frame over the journal box.

Axle #3 lateral acceleration measured on the truck frame over the journal box.

ii) Truck Pitch

Rear Truck - vertical displacement was measured over all four primary suspensions. The data was processed to produce truck pitch.

All data measured was recorded on magnetic tape, and the four parameters described above were also recorded on paper chart recorders.

Parameters for Unit 6923 were also recorded, but are not part of this report.

A more complete description of the instrumentation is includded as Appendix 3.

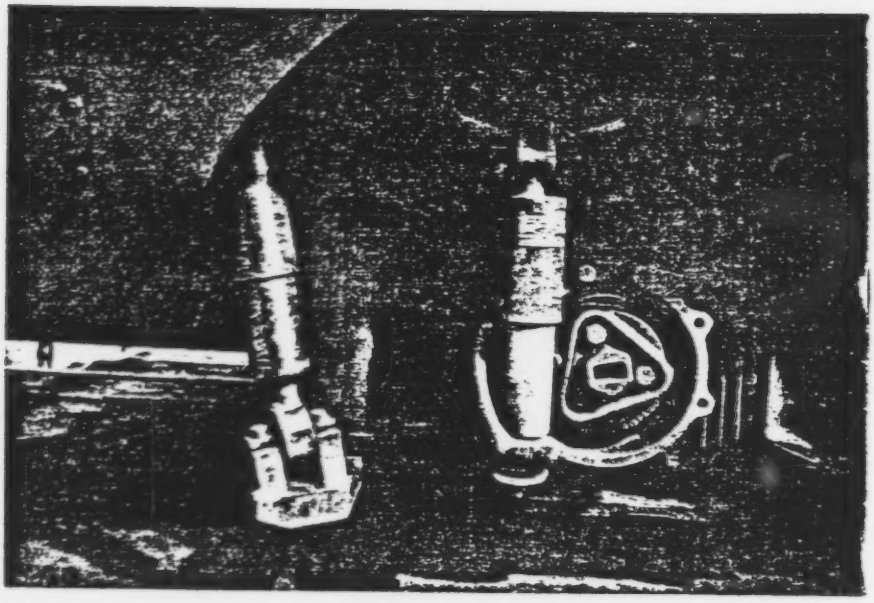


Fig. 4 - Truck Photograph
(Note secondary outboard location).

3.4 Test Schedule

The schedule of tests completed on Sept. 29, 1986, is described as follows:

Run	Direction	MP	Indicated(*) Speed	Rail Cond.
1	Westbound	69-103	105.5	wet (dew)
2	Westbound	159-170	95.5	dry
3	Eastbound (9:42 am)	170-159	95.5	dry
4	Eastbound (1:20 pm)	170-159	95.5	dry
5	Eastbound	103-69	106	dry
6	Westbound (3:25 pm)	69-103	106	dry

(*) The speeds were taken from the left hand side speedometer of Locomotive #6930. This was calibrated using a stopwatch, at 95 mph, on the way to the test area. The speedometer readings were consistently high by 1 MPH, and agreed with the speedometer in Unit 6923. Mile posts and second markings were also recorded on the chart recorder. The clock on the chart recorder was frequently dependent, i.e., engine speed dependent, and could be randomly off by several percent. On test No. 6, a milepost timing check was done that showed that the true speed was 103 mph while the clock showed 106 mph. This discrepancy remains unexplained. True speeds will be in the range of 1 to 3 mph less than indicated speed.

3.5 Note on Maximum Speeds.

It was not possible to achieve the target speed of 110 mph. Difficulty was experienced in defeating the overspeed limit safety controls. Considerable time was wasted on the test day through a series of mechanical problems that were not associated with the test itself. The result was that there was not sufficient time to resolve the overspeed limit problems.

Maximum speeds achieved were in the 103-104 mph range.

3.6 Drop Test

A drop test was conducted by Dofasco at the Via Rail, Ville St-Pierre Maintenance Shops, on Sept. 30, 1985. This test consists of jacking and quickly releasing one corner of the truck. Truck pitch amplitude and frequency can be obtained by processing the displacements measured at the four journal boxes. Three tests were conducted; one with all vertical dampers in place, one with primary verticals only, and one with no vertical damping.
Results are discussed in Sect. 4.3

4.0 Test Results

In discussing the results, reference is made to Unit 6923 as well. Unit 6923 was equipped with Koni yaw dampers only, and had conventional chevrons. It is not part of the TDC program, but is referred to as required, to clarify or reinforce conclusions reached concerning the new chevrons on Unit 6930.

4.1 MP 162-170, North Track, 95 mph.

The test program included running over MP 162-170, north track, at maximum track speeds, where hunting had been encountered on the previous test runs of Aug 22, 1985, and Sept. 22, 1985. The test conditions were, with the exception of intervening track wear, identical to those of the two previous tests.

The results are shown in Fig. 5. It is seen that the hunting has been eliminated. To further illustrate the progress that has been made, a sample of the hunting that was measured in August, 1982, when the hunting problem was first discovered, is shown in Fig. 6. (Please note the changes in scales). No other occurrences of hunting of Unit 6930 over this test section were encountered.

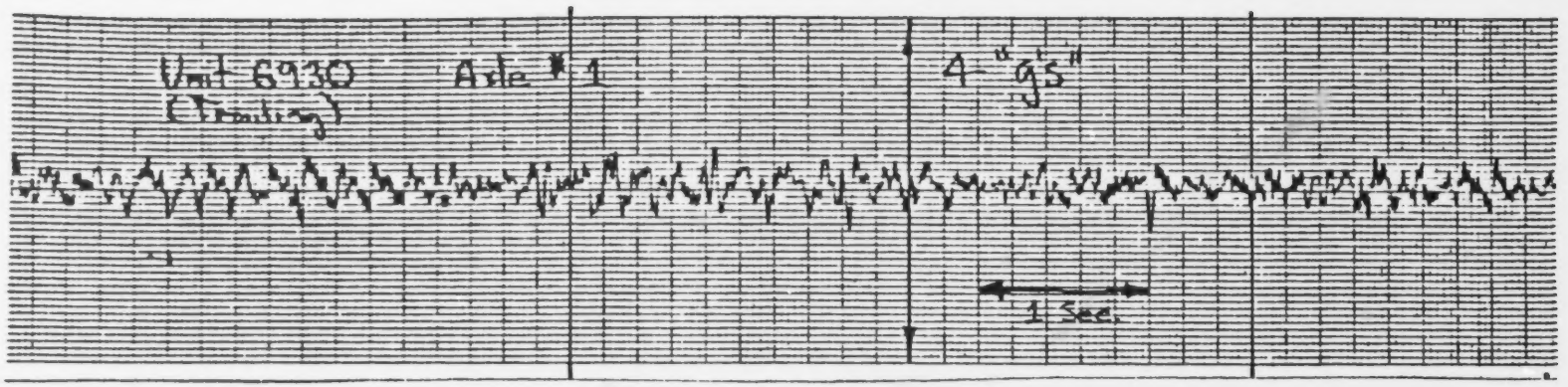
4.2 MP 86.5, North Track, 103 MPH.

No occurrences of hunting were encountered with Unit 6930. Unit 6923 experienced several bursts of "sub-hunting activity", the most serious of which is shown in Fig. 7. The most active axle of 6930, over this same section of track was Axle #1. This is also illustrated in Fig. 8. It is seen that, although there is some response to the track input at this location, the peak accelerations are less than half those for Unit 6923, Axle #3, and no characteristic sinosoidal motion is present.

Unit 6923 is marginally hunting, at this one point only according to the criteria listed in Appendix 1. Unit 6930 is definitely not hunting.

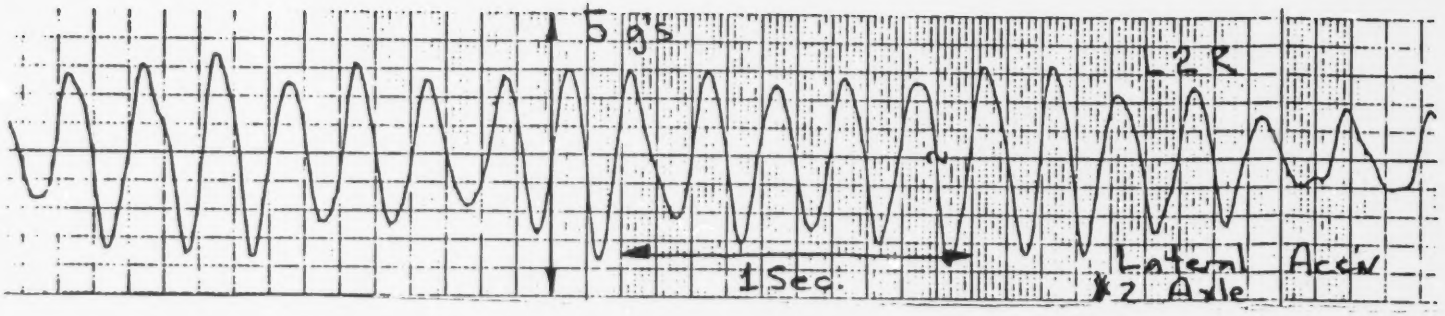
4.3 Drop Test

The drop test results are included here because of the importance of not increasing the pitch natural frequency to the acceptance of the new chevrons. The most important result is that for the drop with no dampers attached, as this determines most clearly the pitch natural frequency.



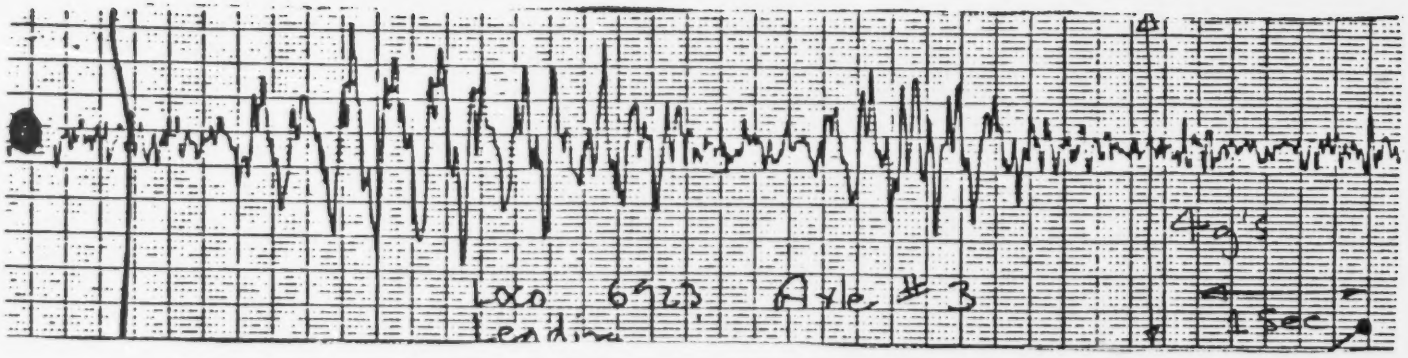
Unit 6930 - Axle No. 1
- Locomotive Trailing
- M.P. 166.5, North Track
- Speed 95 mph
- Dry Rail
- Filtration 15 Hz
- New Primary Suspension Chevrons and New Yaw Dampers.

Fig. 5 Lateral Acceleration Sample
High Speed Test
Sept. 29, 1985.



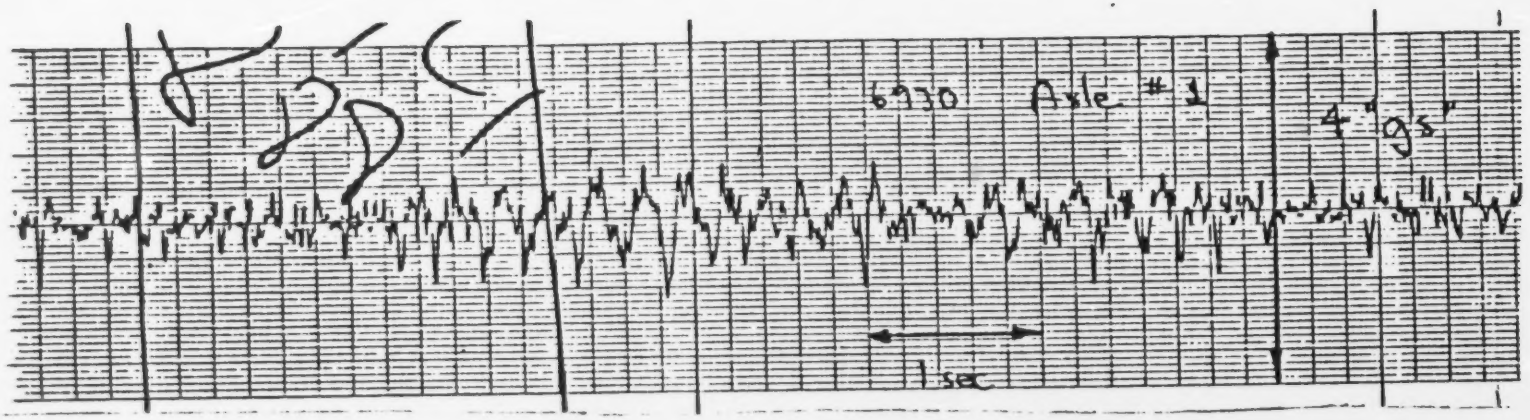
Unit
- Axle No. 2
- Locomotive Trailing
- M.P. 88
- Speed 95 mph
- Dry Rail
- Filtration Level 10 Hz
- Locomotive in "as shipped" Condition.

Fig. 6
- Hunting Sample
- Aug. 28, 1982.



Unit 6923
- Axle No. 3
- Locomotive Leading
- M.P. 86.5
- Speed 104 mph
- Filtration Level 15 Hz
- Dry Rail
- New Yaw Dampers O Oy

Fig. 7 - Marginal Hunting Activity
Unit 6923
High Speed Test, Sept. 29, 1985.



Unit 6930 - Axle No. 1
- Locomotive Trailing
- MP 86.5
- Speed 104 mph
- Filtration Level 15 Hz
- Dry Rail
- New Chevrnons and Yaw Dampers

Fig. 8 - Lateral Acceleration Sample, Unit 6930
High Speed Test
Sept. 29, 1985.

The recording for this drop is illustrated in Fig. 9. The results are summarized as follows:

Truck Pitch Natual Frequency:

- with conventional chevrons 6.50 Hz
- with the new chevrons (Metalastik 17/1153, 16 x 45) 6.53 Hz.

It is seen that the actual effect on pitch frequency is less than would have been predicted from the lab tested results shown in Table 2.

4.4 Wheel/Rail Profiles

The wheel profiles from 6930, and the rail profiles at MP 165.5 (hunting site) and MP 77.5 (non-hunting site) have been measured by CN Research so that the effective conicities for the locomotive at these sites can be determined. The effects of the suspension change will be studied during the analytical phase of the program in an effort to better understand the phenomenon of hunting.

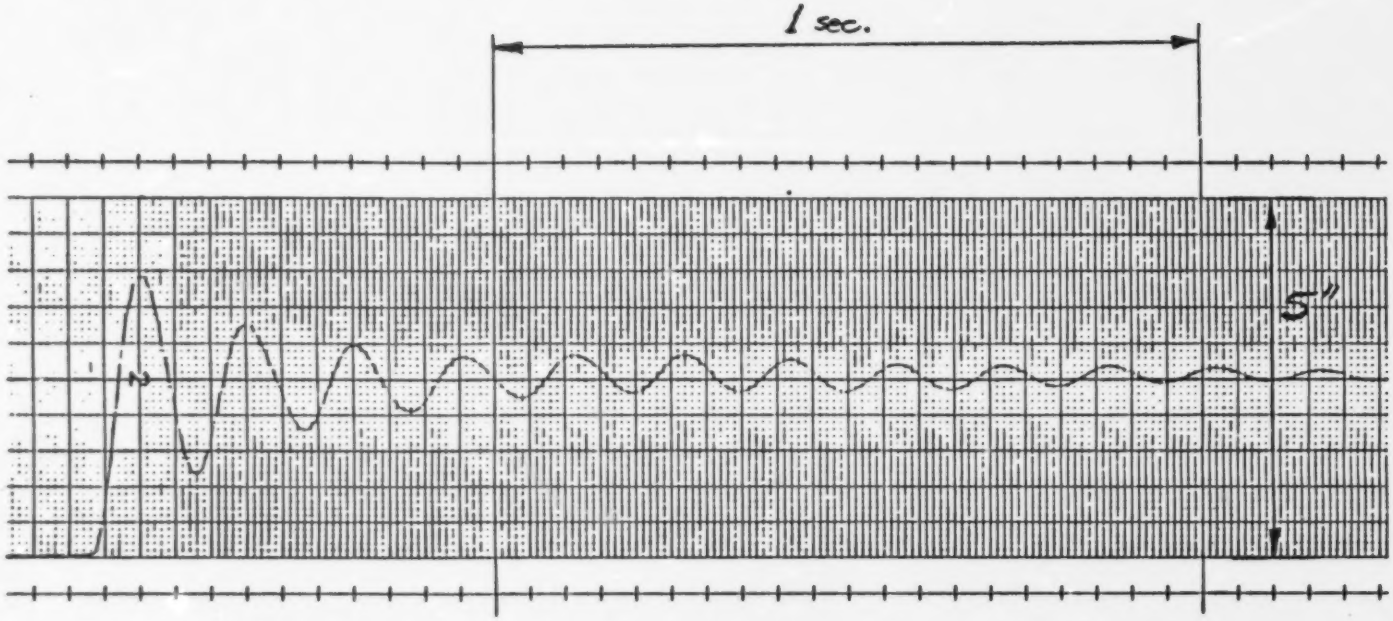


Fig. 9 - Drop Test Results
All Vertical Dampers Removed
Sept. 30, 1985

5.0 Conclusions

The principal conclusion is that the addition of the stiffer primary suspension chevrons has a definite stabilizing effect on the LRC Locomotive. It can be deduced from the results that the stability margin is increased by at least 10 mph, and probably more. The logic for this is as follows:

i) at MP 162-170

Unit 6930 was definitely unstable at 95 mph when equipped with new secondary yaw dampers only. Unit 6923, similarly equipped, showed no signs of instability over same track section on Sept. 29, 1985.

ii) at MP 86.5

Unit 6930, with the new chevrons plus the new yaw dampers, was stable at this point while Unit 6923 was marginally unstable.

In other words, 6930 was taken from being less stable than 6923 at 95 mph, to being more stable than 6923 at 103 mph, by the addition of the chevrons.

The conclusion reached by Bombardier is that the combination of new secondary yaw dampers and new primary chevrons represents the technical solution to the LRC locomotive truck problems. Unit 6930, at time of writing, remains in revenue service at operating track speeds, and is monitored periodically to ensure continued stability.

Because the testing of these chevrons was done during the high speed tests, rather than at track speeds, as had been originally planned, it was possible to better evaluate their effect on stability.

It is also apparent from the test results that there can be considerable variation in performance between apparently identical trucks. During the course of the LRC program testing, six trucks were monitored to, or beyond, 50,000 miles. Only one of these was unstable at operating speeds. It is hoped that a better understanding of this phenomenon can be achieved during the analytical portion of the test program, where the field measurements of effective conicities and vehicle performance will be used to calibrate the mathematical model.

APPENDIX 1

LIST OF HUNTING CRITERIA

LRC Locomotive Truck Dynamics Program
Hunting Criteria
Sept.20,1985

1. Definition

1.1 Hunting is defined as a continuing limit cycle oscillation of the wheelsets, at ten hertz or less,that excites the truck frame in a periodic fashion through the primary suspension, and is characterized by flange to flange contact.

1.2 Lateral oscillations of the wheelsets at the hunting frequency can be excited by rail joints, switches, track perturbations at level crossings,etc.If there are less than five limit cycle oscillations following such an event, the truck is not considered to be hunting.When oscillations persist at the rail joint input frequency, on jointed track, close examination of the actual test results will be required to establish whether or not the truck is hunting.

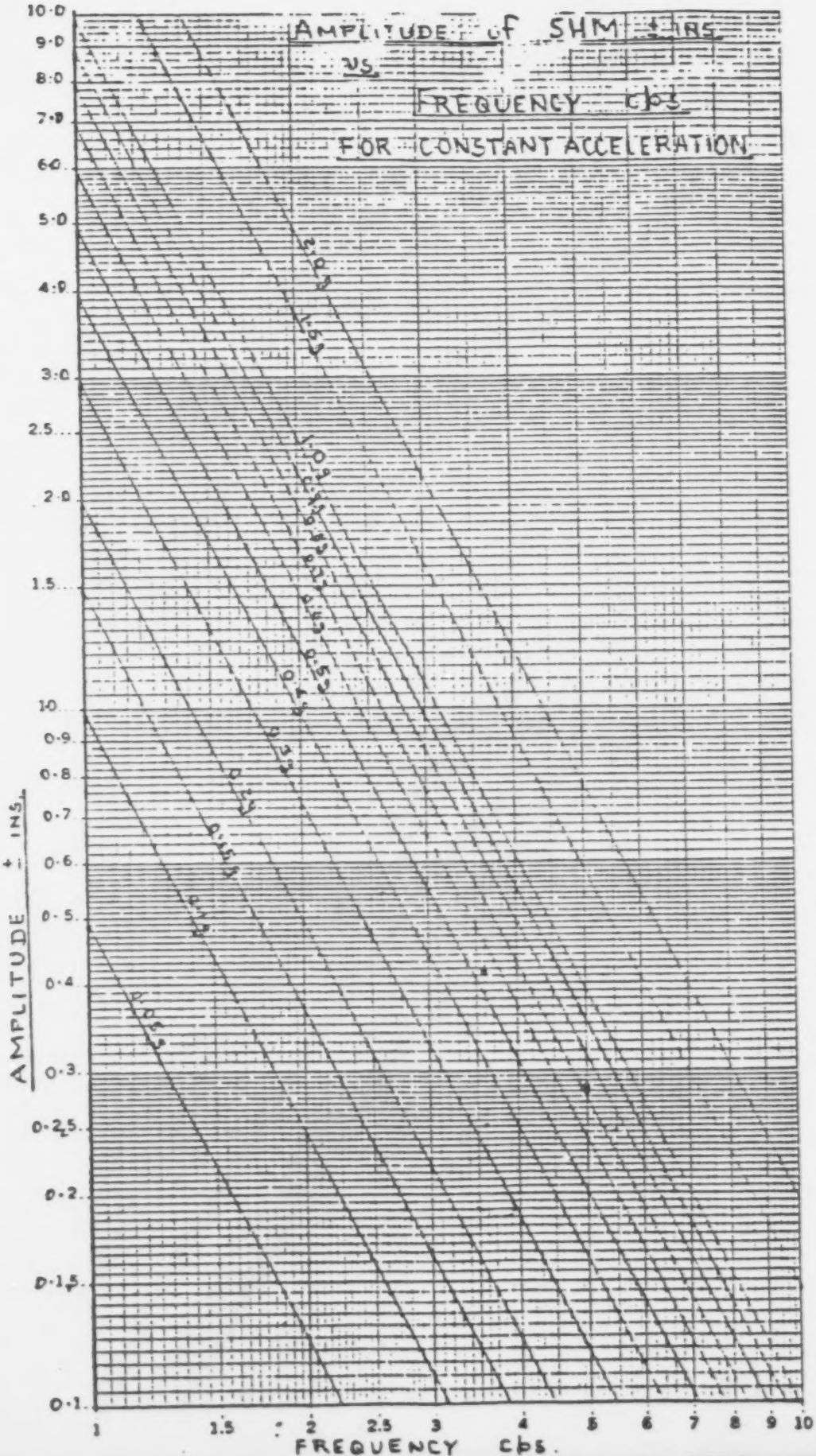
1.3 When the limit cycle oscillations persist for five cycles or more, without obvious external excitation, the vehicle is consider to be hunting.

1.4 The hunting signal may be characterized as a single frequency oscillation or by several frequencies close together that show a distinct beating pattern.

2. Measurement

2.1 Because of the difficulty in directly measuring axleset displacements, relative to the rail, an indirect method is used. A lateral accelerometer is mounted over the journal box an the truck frame, and the lateral accelerations are measured. The signals are filtered at the 10 hertz level to remove higher frequency accelerations that are present in the signal but do not lead to important displacements, and are therefore not of interest.

2.2 To the extent that the filtered lateral accelerations approximate SHM, the amplitude of the truck frame at the point of measurement can be calculated from the peak amplitudes and frequencies measured. The assumption is made that the motion at the point of measurement on the truck frame closely approximates the motion of the journal box.



46 7083
K·E LOGARITHMIC 2 × 1 CYCLES
KEUFFEL & ESSER CO MADE IN U.S.A.

2.3 It is valid to reduce the measured acceleration by an appropriate amount if acceleration components at other than the hunting frequency are present in the signal.

2.4 The phase relationships between the axles will determine the nature of the truck frame motion (i.e. yaw, lateral, or some combination thereof) but is not required to be known under the terms of this definition.

2.5 The actual flangeway clearance depends on many factors, such as wheel flange thickness, wheel wear, track gauge, dynamic rail motion under load, etc. It is not possible at any given point in time to establish whether the actual flangeway clearance is being exhausted, using the SHM calculation. It is generally accepted however, that the clearance will be somewhere between 0.25 ins. and 0.40 ins.

3. Criteria

3.1 When the derived wheelset motion is less than 0.25 ins. (plus/minus), the truck is not hunting.

3.2 When the derived wheelset motion is greater than 0.40 ins. (plus/minus), and all the other requirements of the definition are met (Sect.1, above), the truck is hunting.

3.3 When the derived wheelset motion is inbetween 0.25 and 0.40 ins., and the other requirements of the definition are met (Sect.1, above), a decision will be taken as to whether or not the vehicle is hunting, based upon past experience and the collective judgement of the engineers involved.

The attached nomogram will be useful in relating measured accelerations and frequencies to displacements, where SHM is approximated.

APPENDIX 2

KONI YAW DAMPER TEST RESULTS

KONI America Inc.
A Subsidiary of ITT
PO Box 40
Culpeper, Va. 22701
Tel (703) 825-4543.Twx 822454

September 17, 1985

David D. Taylor & Associates Inc.
c/o Bombardier Limitee
Rail and Diesel Products Division
1505 Dickson St.
Montreal, Que. Canada H1N 2H7

Dear Mr. Taylor:

In reference to the four dampers 04R-1131-001 submitted to KONI America for test and evaluation the results are as follows:

Test Values September 11, 1985

Serial Number	20,000N 0.025 M/Sec	21,500N 0.05 M/Sec	24,350N 0.1 M/Sec
103	17,000/17,500 N	20,000/21,000N	23,000/24,000N
105	17,000/18,000N	19,500/21,250N	22,500/24,000N
106	15,500/16,250N	17,500/18,500N	20,000/21,250N
108	19,250/18,750N	22,000/22,500N	24,500/25,000N

Production Values July 1984

Serial Number	20,000N 0.025 M/Sec	21,500N 0.05 M/Sec	24,350N 0.1 M/Sec
103	19,500/20,100N	21,350/21,750N	24,000/24,500N
105	20,100/20,100N	22,000/21,500N	23,750/24,500N
106	19,500/20,000N	21,250/22,000N	23,000/24,500N
108	19,500/20,000N	21,000/21,500N	23,600/24,250N

Analysis of the force/velocity characteristics indicates that the dampers are performing within their design envelope. The reduction in damping forces may be attributed to normal initial wear or perhaps slight movement of the external adjustment screw. It should also be noted that it would have been advantageous to have tested the dampers at 50mm of stroke. The machine used for the tests does not have the capacity for lower RPM so the stroke was adjusted accordingly.

KONI wishes to wait for the final test data prior to making a commitment for a design of a higher capacity damper. The rigidity of the mount brackets and truck frame must also be considered as an important factor in the overall design.

The dampers are being returned to Bombardier with the same adjustment as received. If necessary they may be recalibrated at a latter date.

Should additional information be needed please feel free to contact me.

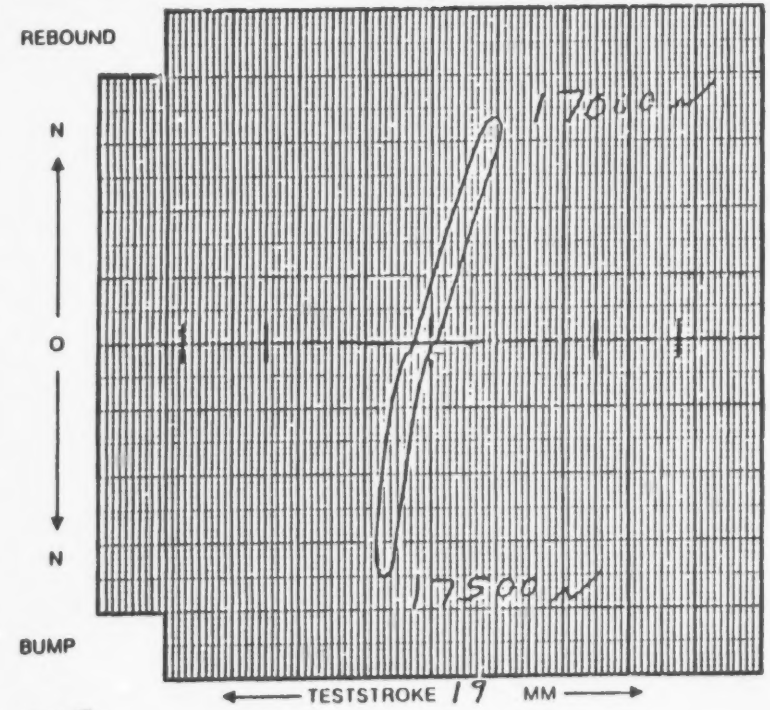
Very truly yours,

James F Vance

James F. Vance
Manager, Commercial Vehicle
Product Development and Sales
Support Group

JFV/lms

Shock Abs. Type: 04R-1131-001
Date code: 7-84
Serie-Nr. : 103
Date: 9/11/85
.025 m/sec



n = 25 r.p.m.
1 mm = 500 N

PISTONROD Ø: PISTON Ø:

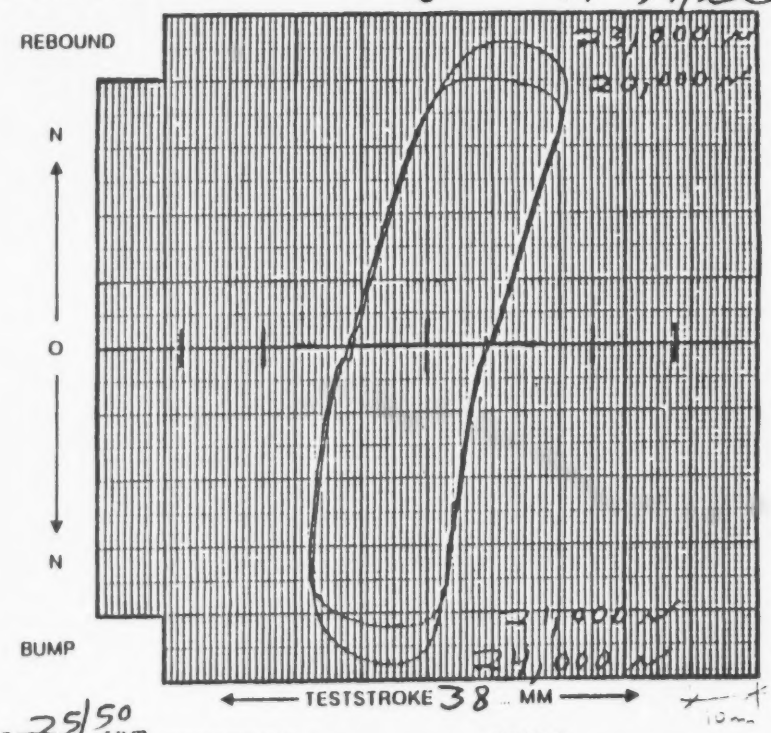
PISTONROD: X CONST.: GUIDE/PISTON X

BYPASS: X SPRING: VALVE:

UPSTREAM: X UPSTREAM SPRING: X 0,

BOTTOM VALVE: ADJ NUT:

Shock Abs. Type: 04R-1131-001
Date code: 7-84
Serie-Nr. : 103
Date: 9/11/85
.05 m/sec
.1 m/sec



n = 25/50 r.p.m.
1 mm = 500 N

PISTONROD Ø: PISTON Ø:

PISTONROD: X CONST.: GUIDE/PISTON X

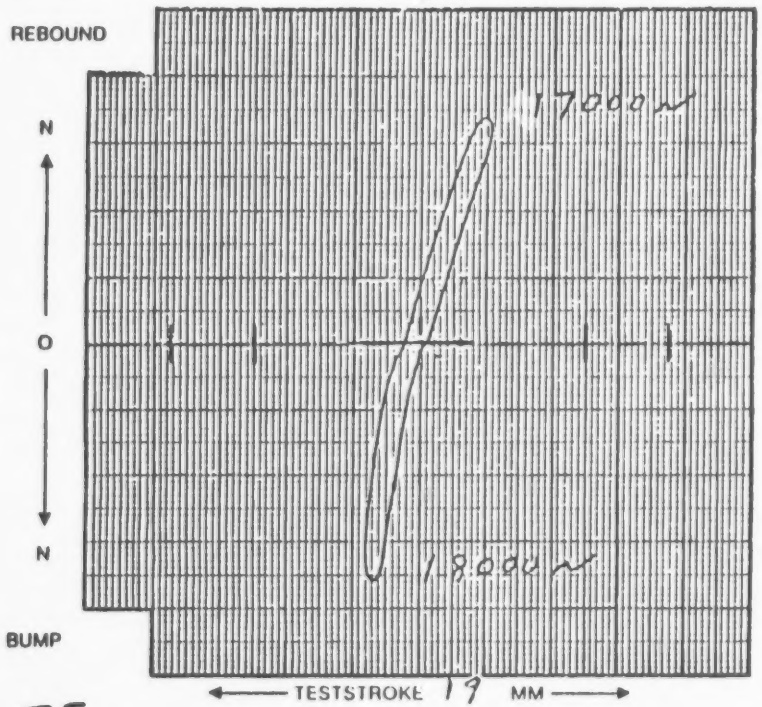
BYPASS: X SPRING: VALVE:

UPSTREAM: X UPSTREAM SPRING: X 0,

BOTTOM VALVE: ADJ. NUT:

Shock Abs. Type 04R-1131-001
Date code: 7-84
Serie-Nr. : 105

Date: 9/11/85
.025 m/sec



n = 25 r.p.m.
1 mm = 500 N

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PISTONROD: ..... X ..... CONST.: GUIDE/PISTON ..... X .....

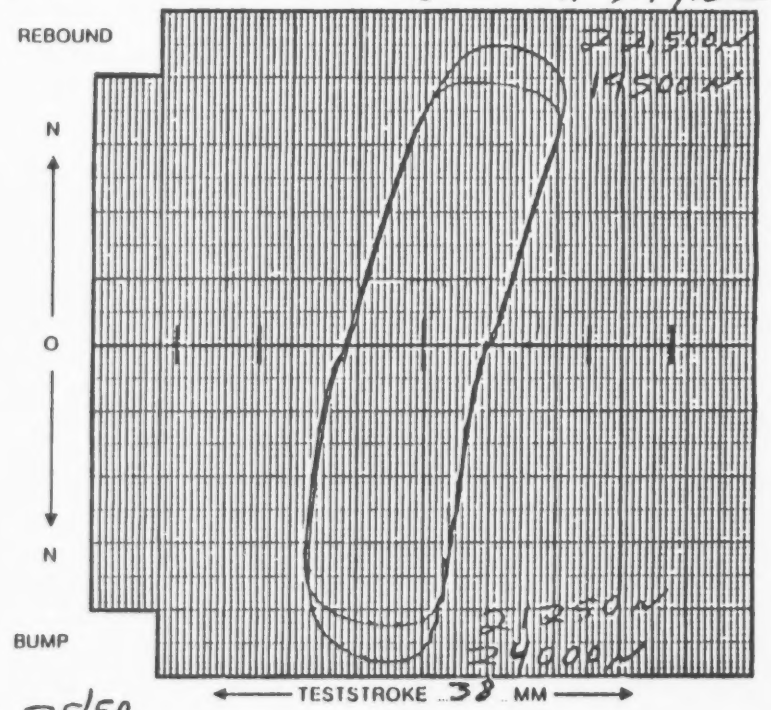
BYPASS: ..... X ..... SPRING: ..... VALVE: .....

UPSTREAM: ..... X ..... UPSTREAM SPRING: ..... X 0, ...

BOTTOM VALVE: ..... ADJ. NUT: .....

Shock Abs. Type 04R-1131-001
Date code: 7-84
Serie-Nr. : 105

Date: 9/11/85
.05 m/sec
.1 m/sec



n = 25/50 r.p.m.
1 mm = 500 N

PISTONROD Ø: ..... PISTON Ø: .....

PISTONROD: ..... X ..... CONST.: GUIDE/PISTON ..... X .....

BYPASS: ..... X ..... SPRING: ..... VALVE: .....

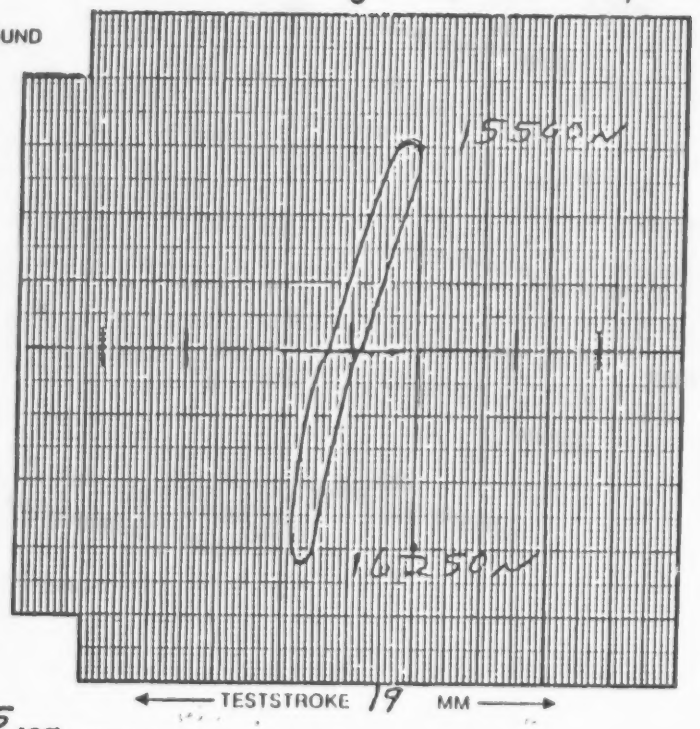
UPSTREAM: ..... X ..... UPSTREAM SPRING: ..... X 0, ...

BOTTOM VALVE: ..... ADJ. NUT: .....

Shock Abs. Type: 04R-1131-001
Date code: 7-84
Serie-Nr. : 106

Date: 9/11/85

.025 m/sec



n = 25 r.p.m.
1 mm = 500 N

PISTONROD Ø: PISTON Ø:

PISTONROD: X CONST.: GUIDE/PISTON X

BYPASS: X SPRING: VALVE:

UPSTREAM: X UPSTREAM SPRING: X 0,

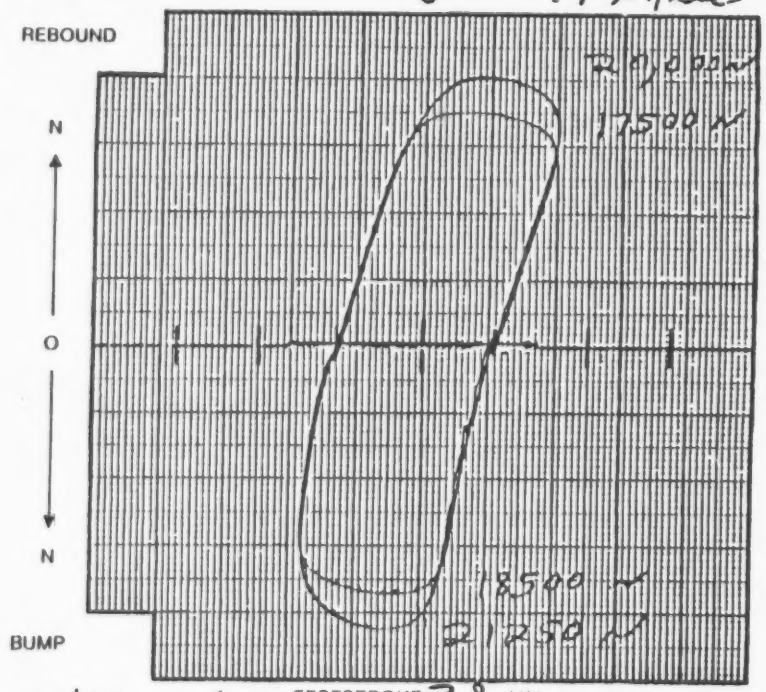
BOTTOM VALVE: ADJ. NUT:

Shock Abs. Type: 04R-1131-001
Date code: 7-84
Serie-Nr. : 106

Date: 9/11/85

.05 m/sec

.1 m/sec



n = 25/50 r.p.m.
1 mm = 500 N

PISTONROD Ø: PISTON Ø:

PISTONROD: X CONST.: GUIDE/PISTON X

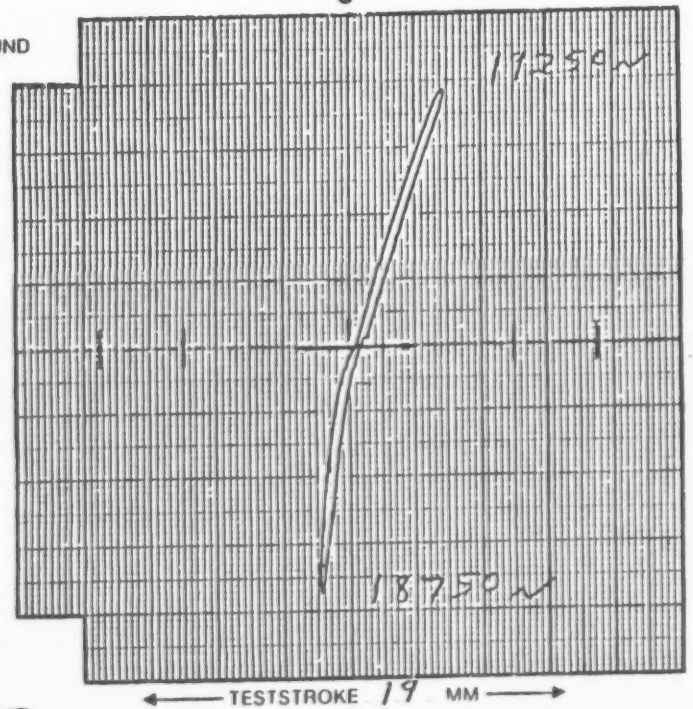
BYPASS: X SPRING: VALVE:

UPSTREAM: X UPSTREAM SPRING: X 0,

BOTTOM VALVE: ADJ. NUT:

Shock Abs. Type: 04R-1131-001
Date code: 7-84
Serie-Nr. : 108

Date: 9/11/85
.025 m/sec



n = 25 r.p.m.
1 mm = 500 N

PISTONROD Ø: ..... PISTON Ø: .....

PISTONROD: X CONST.: GUIDE/PISTON X

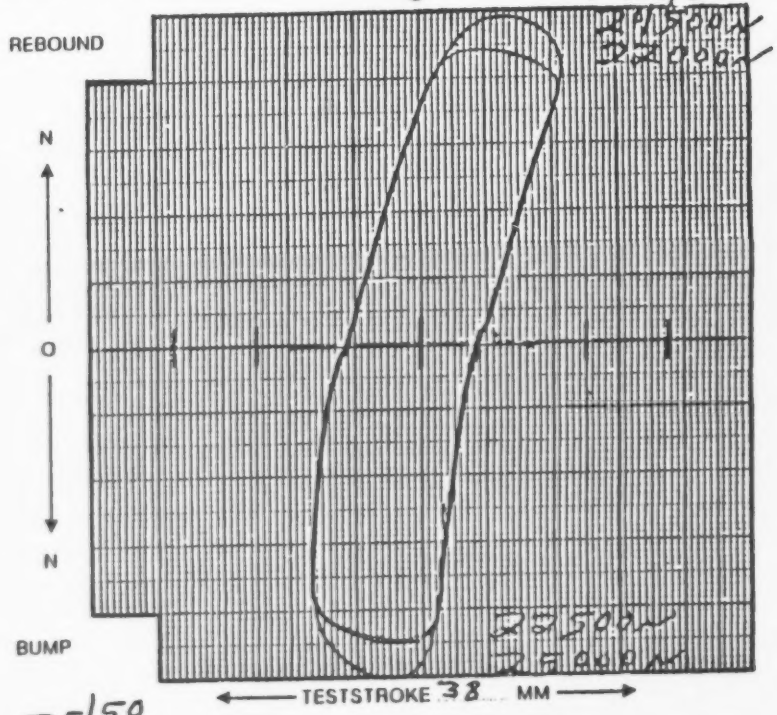
BYPASS: X SPRING: VALVE:

UPSTREAM: X UPSTREAM SPRING: X 0,

BOTTOM VALVE: ADJ. NUT:

Shock Abs. Type: 04R-1131-001
Date code: 7-84
Serie-Nr. : 108

Date: 9/11/85
.05 m/sec
.1 m/sec



n = 25/50 r.p.m.
1 mm = 500 N

PISTONROD Ø: ..... PISTON Ø: .....

PISTONROD: X CONST.: GUIDE/PISTON X

BYPASS: X SPRING: VALVE:

UPSTREAM: X UPSTREAM SPRING: X 0,

BOTTOM VALVE: ADJ. NUT:

APPENDIX 3

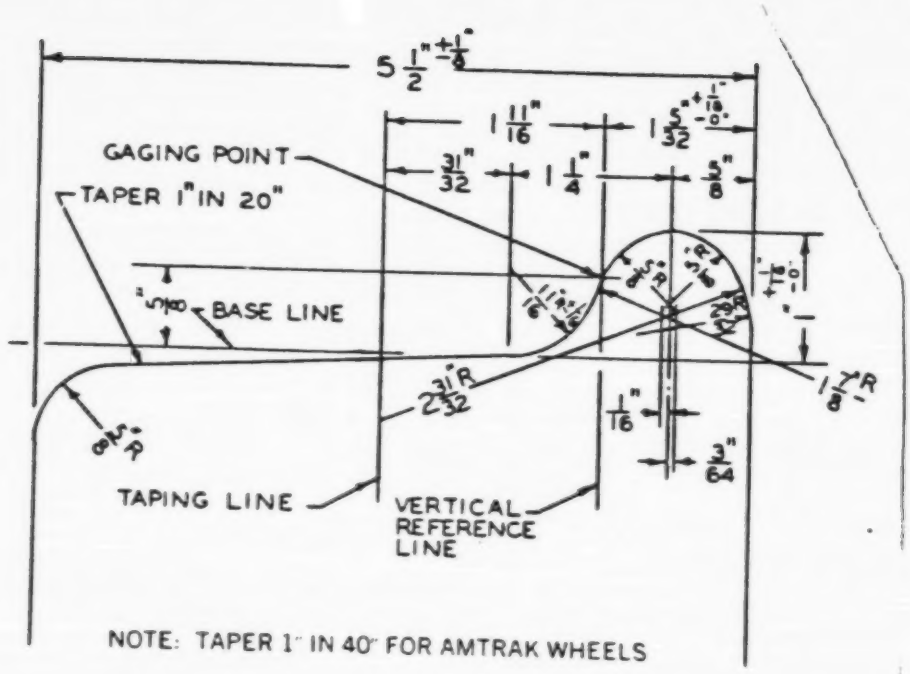
TEST INSTRUMENTATION

Instrumentation for 110 mph
stability test

Channel #	Locomotive #	Instrumentation
1	6923	Lateral accelerometer on rear truck above Axle 3 (4g F.S.)
2	6930	Truck pitch displacement of rear truck (5 inch F.S.)
3	6930	Lateral accelerometer on front truck above Axle 2 (4g F.S.)
4	spare	spare
5	--	Train speed (mph)
6	6930	Lateral accelerometer on front truck above Axle 1 (4g F.S.)
7	6930	Lateral accelerometer on rear truck above Axle 3 (4g F.S.)
8	6923	Lateral accelerometer on front truck above Axle 1 (4g F.S.)

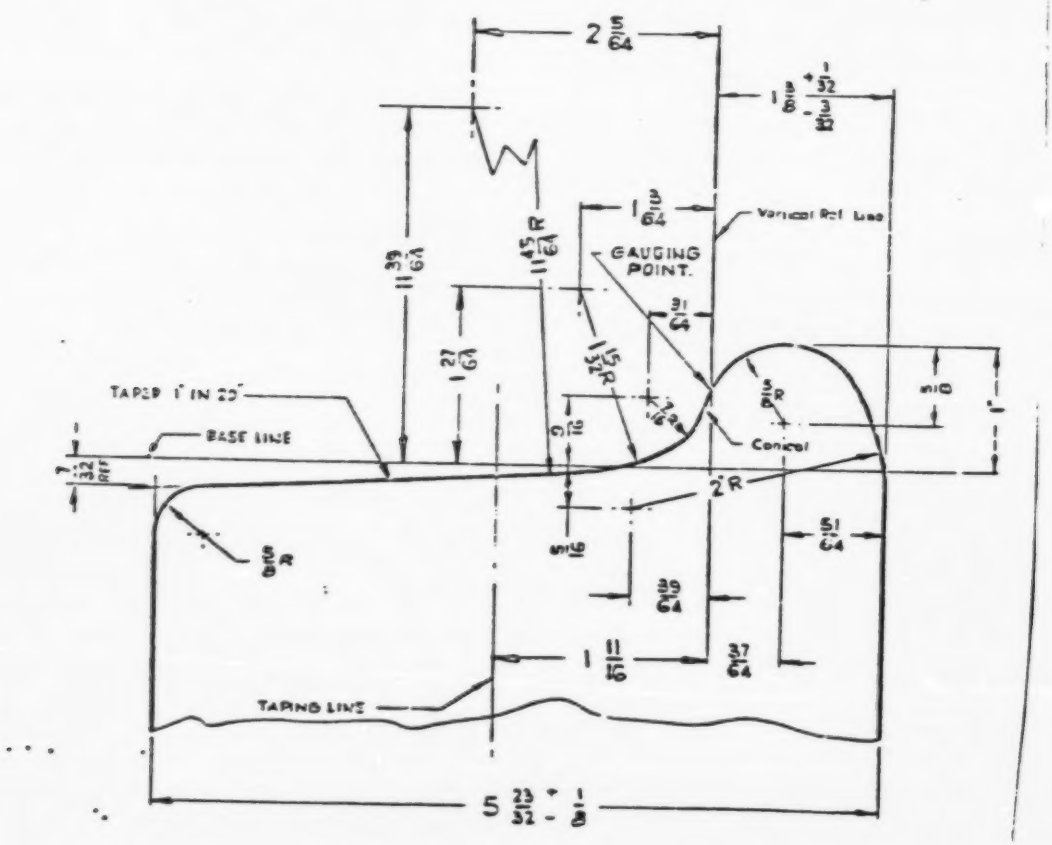
APPENDIX 4

WHEEL PROFILES



NOTE: TAPER 1" IN 40" FOR AMTRAK WHEELS

AAR 1:40 NF



CN MODIFIED HEUMANN

APPENDIX III

Interim Report #2

Literature Review Report

PROJECT NO. 439300

REPORT NO. 2

Bombardier Inc.

Rail and Diesel Power Products Division

MONTREAL CANADA

TRANSPORTATION ENGINEERING

DEVELOPMENT SECTION

SUBJECT TDC Wheel/Rail Interaction Program
Contract No. OSD84-00277.

Interim Report No. 2.

Literature Review Report.

COMPILED BY: David D. Taylor
David D. Taylor, P. Eng.
David D. Taylor & Assoc.Inc.

APPROVED BY: R. S. Bergner

DISTRIBUTION

SUMMARY

FULL REPORT

LIBRARY REF. NO: 439320

DATE: March 7/86

TDC WHEEL/RAIL INTERACTION PROGRAM

INTERIM REPORT No. 2

LITERATURE REVIEW REPORT

1.0 Purpose

One of the principal aims of the program is to use the DYNSYM computer model to examine the effect of wheel/rail geometry and vehicle suspension design on vehicle stability, using the LRC locomotive as the reference vehicle. Data acquired during the LRC locomotive field testing program is to be used to calibrate the computer model.

One of the tasks identified in the program was to complete a survey of all relevant literature in the area, before commencing on the analytical work. This survey was expected to yield valuable references, ideas, and data, that would be useful in the planning of the analytical work. This survey has now been completed, and constitutes the body of this report.

2.0 Procedure.

The T.D.C. Library provided the author with an exhaustive title search of papers in the general area of wheel/rail interaction. This list had been compiled by someone working on another T.D.C. sponsored program.

A total of twenty titles was selected. Of these, twelve were available, and were obtained by the Library. Two of these proved not to be relevant. The remaining ten have been individually reviewed, and are included in Sec. 4.

3.0 Summary of Principal Findings.

There was a general consistency to the contents of the various papers. A brief summary is included here under the following headings:

i) General Observations/Conclusions.

ii) Useful Wheel/Rail Information.

iii) Things to watch for in the Analysis Portion of the Program.

3.1 General Observations/Conclusions.

a) There is a clear consensus that non-linear mathematical models, such as DYNSIM, are required to study vehicle hunting, which is essentially a non-linear phenomenon.

b) All observers agree that wheelsets wear quickly to a quite uniform worn profile. The choice for the vehicle designer is clear: design the vehicle to perform well with a worn (conformal) profile, or maintain a tapered profile through frequent re-machinings.

c) The strong stabilizing effect of moisture on rails is referred to several times. It is concluded that creep coefficients are highest on clean dry rail, and that high creep coefficients are destabilizing.

d) It is observed that wheelset behavior for a given vehicle is very repeatable over the same section of track at the same speed. This is in agreement with LRC field measurements.

e) The relatively low adhesion value required to transmit tractive effort at high speeds is held to have minimal effect on the lateral creep coefficients, and hence on stability.

f) Tread wear is observed to not be reduced by the use of conformal profiles. The saving in tread metal comes from the reduced amounts that have to be machined off to re-establish the flange profiles. Flange wear to date on the LRC has been minimal. The implication of this is that the WF profile on the LRC wheels may not give longer wheel life than a NF Heumann profile would.

g) It was observed in one paper that the rear truck was shown in the modelling to be less stable than the front truck. This has been observed in the field for the LRC locomotive, although no explanation for this has thus far been developed.

h) The following factors were observed to have an effect on effective conicity:

   i) rail cant (close to vertical is destabilizing)

   ii) the combination of rail cant and wheel taper

   iii) track gauge (tight gauge is destabilizing)

iv) rail head and wheel tread radii.

The critical hunting speed was stated to be inversely proportional to the square root of the effective conicity.

3.2 Useful Wheel/Rail Information.

a) Effective Conicities.

Effective conicities are reported, based upon field measurements by various European railways, ranging from 0.01 to 0.70. Values depend on the combinations of parameters listed in 3.1 h) above.

British Rail report a range of values between 0.05 and 0.50 for the same wheelset on a variety of rails, indicating the sensitivity of effective conicity to rail geometry.

b) Total Flangeway Clearances.

Ranges of flangeway clearance between 5 mm and 24 mm are reported. The tendency seems to be to limit the clearance thus reducing large amplitude wheelset

oscillations that could excite primary (body) hunting, eventhough this may increase the effective conicity.

3.3 Things to study, in the Analysis Portion of the program:

a) the effect of rail cant, side-to-side rail cant variation, and the combination of rail and wheelset tapers on effective conicity and hence on stability.

b) the effect of varying flangeway clearance on stability, keeping in mind 3.2 b) above.

c) the effect of track gauge on effective conicity and hence on stability.

d) the effect of varying the primary suspension lateral and longitudinal rates on vehicle stability.

e) the effect of secondary suspension yaw damping on vehicle stability.

4.0 Reviews of Individual Papers.

4.1 Title List.

Sect.	Paper No.	Title
4.1.1	1	Measurements and Observations on Wheelset Lateral Dynamics of Locomotives on Tangent Track. R. Kummrow Swiss Locomotive and Machine Works.
4.1.2	2	The Influence of Rail Head Geometry and Cant Angle Variation on Rail Vehicle Dynamics. N.K. Cooperrider Q. He Arizona State University.
4.1.3	3	Influence of Vehicle/Track Interface Characteristics on Vehicle Dynamics. SNCF Experience. A. Moreau SNCF
4.1.4	4	Heumann Tyre Profile Tests on British Railways. J. L. Koffman British Railways
4.1.5	5	Geometry of the Contact Between Wheelset and Track: Equivalent Conicity Values for Vehicles in Service. Anon
4.1.6	6	Influence of Wheel/Rail Profiles on the Hunting Vibrations of Rail Vehicle Trucks. A. F. D'Souza W. J. Tsung Illinois Institute of Technology.
4.1.7	7	Vehicle Dynamics and Wheel/Rail Interface Problems. A. H. Wickens British Railways.

4.1.8	8	Improved Wheel Tread Profiles for Heavy Freight Vehicles. P. Marcotte K.J.R. Mathewson W.N. Caldwell Canadian National Railways.
4.1.9	9	Influence of Non-linear Wheel/Rail Contact Geometry on Stability of Rail Vehicles. R. Hull N. K. Cooperrider Arizona State University.
4.1.10	10	New Tyre Profiles for British Railways B. L. King British Railways.

Sect. 4.1.1 - Wheel/Rail Interaction Study.

Literature Review Report.
Paper No. 1.

Title — Measurements and Observations on Wheelset Lateral Dynamics of Locomotives on Tangent Track.

Author — R. Kummrow
Head, Research and Computations
Swiss Locomotive and Machine Works.

Publication — Journal of Dynamic Systems, Measurement and Control
December 1981, Vol. 103.

Summary

This is a useful and well presented paper that describes experiments done by SLM on a Re 6/6 (Bo-Bo-Bo) locomotive to establish wheelset lateral motion under various conditions of speed and primary suspension stiffness.

The instrumentation consisted of infrared transducers that continuously measured wheelset lateral motion with respect to the rail head, and location sensors that enabled test data to be recorded on a spatial rather than a time basis. A 2.5 Km length of test track was used. Wheelset lateral position, wheelset yaw angle, right rail deformation, and rail gauge variation were recorded continuously. It was seen, that at low speeds (10 m/sec) wheelset motions repeated exactly at the same rail locations. The repeatability was still good, although with some random variation at higher speeds (45 m/sec). Amplitudes increased sharply with increasing speeds.

The effects of tractive effort were also studied. The lateral motion is not greatly affected by low levels of tractive effort, but is considerably altered by higher levels (= 0.12 or greater).

The dynamic rail gauge is not greatly affected by the wheelset lateral motion as long as the lateral motion remains linear (no flange contact). Measured values were within plus/minus 2 m at 45 m/sec.

Effective conicities and contact angle differences are calculated for the test vehicle based upon actual rail and wheel profile measurement.

Information of Value to Wheel/Rail Interaction Program

1. The paper concludes that linear analysis methods are not suitable for studying vehicle phenomena involving high speed, flange contact, and track misalignment. Even well maintained track can have important effects on the wheel/rail contact geometry.

   It is the intent of the W/R program to study all of these phenomena, using the non-linear DYNSIM program, acquired from Railway Engineering Associates.

2. A set of effective conicity data is presented, that is based upon actual wheel and rail profile data. (Rail, moderately worn UIC 54E, rail profile, new SFR-28-II, similar to ORE S1002, rail cant angle 1:40).

   The following can be derived from the data given:

   effective conicity = 0.167

   (linear within flangeway clearance).

   = 2.0
   (with flange contact).

   nominal flangeway clearance = plus/minus 6 mm (pl/min.0.26").

   This is obviously a non-conformal type profile.

3. The damping ratio of the wheelset lateral motion decreases rapidly as the critical speed of the wheelset is approached. This highlights the possible beneficial effect of increasing the primary suspension longitudinal stiffness, to increase the speed at which this damping drops to zero.

4. The effect of moisture on the rail in limiting lateral motion is seen to be dramatic, under stable conditions. Displacements under wet rail conditions are typically reduced by a factor of three.

5. It is shown that dynamic track gauge variation is minimal under conditions of stable lateral oscillations, kinematic or dynamic. Maximum deflections near the critical speed were = 2 mm (pl/min. 0.08 ins.).

6. It is apparent that wheelset lateral motion is site specific, and that response to track input is very repeatable. One of the goals of the W/R program is to try to focus on the rail parameters that induce instability. To this end, rail sites known to induce stable and hunting vehicle behaviour have been measured by CN Research and will form part of the input to the DYNSIM program.

7. It would seem that the low levels of adhesion required by the LRC locomotive, to delivery full power to the rails at 95 mph (= 0.035) are unlikely to have an appreciable effect on the lateral dynamics of the trucks.

Sect. 4.1.2

Wheel/Rail Interaction Study.

Literature Review Report
Paper No. 2.

Title — The Influence of Rail Head Geometry and Cant Angle Variations on Rail Vehicle Dynamics.

Author — Cooperrider, N.K.
He, Quikyong

Publication — Vehicle System Dynamics
Vol. 2, July '83.

Summary

This is a paper that surveys preliminary results of a theoretical study of the influence of rail head geometry and cant angle variations on rail vehicle dynamics. A more complete paper is referred to, but does not yet seem to have been published. The effect of rail cant variation on rolling line offset and longitudinal creep coefficient variation are investigated.

The following parameters are varied:

i) rail head cant (from -0.025 radius to +0.075 radius).

ii) four rail head profiles:

1) as designed, North American 133 lbs/yd.

2) as built, N.A., 133 lbs./yd.

3) worn N.A. rail head, 133 lbs./yd.

4) UIC 60 rail head.

iii) rail gau e (1435 mm pl/min. 6.35 mm) worn N.A. rail head, 133 lb/yd.

iv) four wheel profiles - AAR 1:20 std. profile
- CN profile A
- a high conicity profile developed by the senior author.
- UIC-ORE S1002 profile.

It is shown that a difference in cant between the right and left wheels can have a significant, and reasonably linear, effect on wheelset rolling line offset for either an AAR, 1:20 profile, or a high conicity profile. The same difference can also have an effect on the wheelset longitudinal creep coefficients, although the effect seems to be rather random.

The general statement is made that variations in rail geometry and cant angle along the direction of track can subject vehicles to strong disturbances.

Information of Value to the Wheel/Rail Interaction Program

1. It was found in the field testing phase of the W/R program that the area of track that induced hunting of the LRC locomotive trucks had a noticeably offset pattern of "shiny patch" on the rail surfaces. This would indicate that all traffic passing over this section was not running centrally on the rails. Enough track data was measured by CN Research that it will be possible to establish what the exact track geometry conditions were.

   This paper raises the possibility that a modest cant angle variation from side to side could result in a substantial rolling line offset on the rails and that this could, through some mechanism, induce hunting. This will be studied during the theoretical phase of the program.

Sect. 4.1.3.

Wheel/Rail Interaction Study

Literature Review Report
Paper No. 3

Title — Influence of Vehicle/Track Interface Characteristics on Vehicle Dynamics - SNCF Experience.

Author — Moreau, A.
Eng., Principal, Track Test Division.
Direction de materiel, SNCF.

Publication — Railway Engineering International
Jan.-March, 1980.

Summary

This is a brief, but useful, paper describing the SNCF experience regarding the influence of vehicle/track interface characteristics on vehicle dynamics.

The system of differential equations describing the vehicle behavior are described in a generalized way. The principle of positive roots of the general equations leading to instability is described. Critical speed of the vehicle is also described in terms of damping rates approaching zero.

A criterion of hunting, lateral oscillations at the bogie center exceeding 0.8 g for 1.5 seconds, is described.

The characterization of the lateral wheel rail contact geometry by the expression "equivalent conicity" (or effective conicity) is described, together with the factors that affect it - wheel profile, rail profile, track gauge, flangeway clearance, and rail inclination.

The paper states that a 1:40 wheel profile taper, and a 1:20 rail cant give the best stability results. It states that with the TGV, the equivalent conicity of the wheelsets had not varied after 150,000 kms.

The paper states that the flangeway clearance must be large enough to allow small lateral wheelset displacements without flange contact. SNCF have adapted a gauge of 1437 mm, with a wheelset gauge between running surfaces of 1426 mm, giving a nominal total flangeway clearance of 11 mm. It is stated that too much flangeway clearance can excite the secondary suspension through the wheelset oscillations.

Information of Value to the Wheel/Rail Interaction Program

Stabilizing the truck hunting (or secondary hunting) by increasing the flange clearance is one of the modifications that will be evaluated. Nominal total flangeway clearance for a North American wide flange wheel is 16 mm., and for a narrow flange whee' is 24 mm. The effect of this clearance on bogie hunting (or primary hunting) will be studied as part of the evaluation.

The SNCF experience is that a rail cant of 1:20 is best for low effective conicity. The CN practice is 1:40. This is one of the parameters that will be evaluated in the study.

The SNCF statement that the effective conicity of the 1:40 wheels on the TGV did not change after 150,000 Km, is difficult to accept in terms of North American experience, and must reflect the larger wheels and smaller axle loads.

Sect. 4.1.4.

Wheel/Rail Interaction Study.

Literature Review Report.
Paper No. 4.

Title — Heumann Tyre Profile Tests on British Railways.

Author — J. L. Koffman

Publication — Railway Gazette
April 2, 1965.

Summary

This paper, written in 1965, is perhaps slightly dated, but contains many interesting observations concerning wheel and rail characteristics, and their effect on vehicle stability. the development of a special conformal profile for British Rail by Dr. Heumann is described.

It is noted that any wheel and rail profile quickly wears to a certain shape in service, hence the logic of starting out with a conformal profile and limiting the high initial rate of wear. It is pointed out, that normal running cold works the wheel tread surface and that machining exposes the softer steel below, thereby increasing the initial wear rate after machining.

Various railway practices with respect to flangeway clearance are discussed, and are tabled in the next section. Mr. Koffman feels that this clearance should be as small as possible, and states that the minimum to allow centered top-of-rail contact is 8 mm (5/16 in) total clearance. Other limits to be considered are switch point pick-up and guide rails.

Wear patterns are given for conventional profiles and Heumann profiles. The uniform wear pattern of the Heumann profile is apparent.

Mr. Koffman also discusses at length, the advantages of the conformal type profile over the tapered profile in a general philosophical way, as well as its effect on vehicle ride. Ride indexes rather than hunting are the criteria, however. The potential problems of instability with this profile are not discussed.

Information of Value to the Wheel/Rail Interaction Program

Mr. Koffman states that a 1:20 rail inclination is best for stabilility, provided that it is matched with a 1:20 wheel profile taper. CN rail is canted at 1:40, while the tapered portion of their Modified Heumann profile is tapered at 1:20. The effect of this will be investigated.

Stated total flangeway clearances are as follows: (circa: 1965).

British Rail	18 mm (0.7 ins)
European Practice	10 mm
Some European High Speed Lines	5 mm

As previously stated, Mr. Kauffman feels that reduced flangeway clearance is best for vehicle performance, with a lower limit being 8 mm total. This is different to other opinions that increased flangeway clearance in stabilizing with respect to truck hunting. This will be explored thoroughly in the theoretical portion of the program.

Sect. 4.1.5.

Wheel/Rail Interaction Study.

Literature Review Report.
Paper No. 5.

Title — Geometry of the Contact Between Wheelset and Track: Equivalent Conicity Values for Wheelsets in Service. (2nd part of ORE Report C116/PR3).

Author — Anon.

Publication — Rail International
March, 1978.

Summary

It is stated that realistic effective conicity values can only be derived from actual wheel and rail profile measurements SNCF, DB and BR all have computer based methods of doing this.

Studies were done on SNCF, NS, DB and BR, using the BR apparatus, to develop statistical averages of effective conicities, based upon many rail and wheel measurements.

Rail inclination was as follows:

SNCF and BR	1:20
DB	1:40
NS	changing from 1:20 to 1:40

Results for the various railways are tabled as follows:

Railroad	Effective Conicity Range	Comment
SNCF	0.02 to 0.12 "R" profile (conformal)	Gauge 1428 mm to 1446 mm (nominal std. = 1435 mm)
DB	.14 to 0.70 DB II and DB IIA profiles.	DB II profile was not fully conformal. Conicities reduced with wear. The new DB IIA profile has improved this situation. Other factors leading to high conicity: - tighter gauge. - 1:40 rail inclination
NS	0.05 0.01 0.20 0.39	new 1:20 wheel profile new 1:80 " " most worn wheel values maximum measured values.
BR	0.13 to 0.4 P8	- P8 profile well adapted, little change in conicity with wear. - perpendicular rails (experimental) give high conicity values.

Information of Value to the Wheel/Rail Interaction Program

The table of values above is of great interest as an indicator of ranges of values to be expected, and factors that can affect effective conicity.

The conclusions list the factors that can increase effective conicity. They are as follows:

a) reduced track gauge.
b) inclining rails more nearly to the vertical.
c) filling in the flange root of the wheels.
d) matching wheel and rail cross sectional radii.

The effect of all these will be examined in the analytical portion of the program.

Sect. 4.1.6.

Wheel/Rail Interaction Study.

Literature Review Report.
Paper No. 6.

Title — Influence of Wheel/Rail Profiles on the Hunting Vibrations of Rail Vehicle Trucks.

Authors — D'Souza, A.F.
Tsung, W.J.

Publication — Journal of Vibration, Acoustics, Stress and Reliability in Design.
April, 1985.

Summary

This paper describes a mathematical study, using describing functions to model non-linearities, that examines the effect of a variety of combinations of wheel and rail profiles on the stability of the conventional North American 3 piece freight car truck.

While the mathematical techniques are interesting, the actual values obtained are not realistic, and fly in the face of field experience. For example, the critical hunting speed of the truck with a Modified Heumann profile on new rail is held to be 235 kph (146 mph).

The paper does, however, emphasize the importance of using non-linear analysis methods to study truck hunting, which is a non-linear phenomenon.

Information of Value to the Wheel/Rail Interaction Program

This paper is too theoretical to be of much value. One of its strong conclusions, however, is that rail wear with service is destabilizing. This is contrary to observed experience, and will be looked at in the analytical portion of the program.

Sect. 4.1.7

Wheel/Rail Interaction Study.

Literature Review Report.
Paper No. 7.

Title Vehicle Dynamics and Wheel/Rail Interface Problems.

Author Allen H. Wickens
British Railways Board
Derby, England

Publication Proceedings of Carnegie-Mellon Conference,
May 13-15, 1969, Pittsburgh, Pa.

Summary

This paper gives an excellent fundamental description of the dynamics of a single wheelset on track and discusses the fundamental concepts of effective conicity, creep (lateral, longitudinal and spin), and the effects of these on vehicle stability. The classic trade-off of stability versus curving peformance facing the designer is also discussed at length.

A mathematical development of effective conicity in terms of wheel and rail radii, contact angles, and wheelset moment of inertia is also given.

Mr. Wicken's paper includes a generalized description of other possible types of guidance systems for land vehicles. this is, however, not of specific interest to this project.

Information of Value to Wheel/Rail Interaction Program

1. Damping is shown mathematically to be inversely proportional to the creep coefficient. This means that with clean, dry, rail and high values of creep coefficient, the inherent damping factor of the system is reduced, and the vehicle will have a lowered critical hunting speed.

   This agrees with the observed phenomenon of wet rail, resulting in lowered creep coefficient, improving the stability of the vehicle. It also implies that full creep coefficients should be used in stability analysis as a worst case.

2. The critical speed, for a single wheelset, is shown to be inversely proportional to the square root of the effective conicity.

Normalizing the equation to give a critical speed of 1.0 for an effective conicity of 0.05 gives the following relative values for increasing effective conicity. (Note: These calculations are not included in the Wickens paper).

Effective Conicity	Relative Critical Speed
0.05	1.00
0.10	0.71
0.15	0.58
0.20	0.50
0.30	0.41
0.40	0.35
0.50	0.32
0.60	0.29
0.70	0.27

This calculation is not intended to be rigorous but it does show:

i) the significant effect of effective conicity on critical speed.

ii) the saturation effect with very high values of effective conicity.

3. It is noted that the effect of track gauge on effective conicity is eliminated for purely conical wheels, but has a major effect on effective conicity for conformal type wheels. This is an interesting conclusion, as track gauge has been observed to have a significant effect on truck stability in the field, when the CN Modified Heumann profile is being used.

4. British Rail field testing has shown ranges of effective conicity from 0.05 to 0.50 for a given vehicle with worn treads. Variations in track gauge are held to be a factor in this range. It is interesting to note the wide range of values attributable to the rail condition alone, as the wheelset was constant in these tests. Gauge profile geometry and angle of inclination (cant) will be factors in this.

Sect. 4.1.8

Wheel/Rail Interaction Study.

Literature Review Report
Paper No. 8.

Title — Improved Wheel Tread Profiles for Heavy Freight Vehicles.

Author — P.P. Marcotte
K.J.R. Mathewson
W.N. Caldwell

Canadian National Railways

Publication — A.S.M.E.
Paper No. 80-RT-3.

Summary

This is an excellent and comprehensive paper dealing with the use of conformal wheel profiles as a means of reducing wheel and rail profile wear. Several useful observations are also made concerning high speed stability with conformal profiles. All work pertains to the standard, 3-piece, freight car truck.

The mechanisms of wheel and rail profile change with wear are described. The curving performance of these trucks with standard and conformal profiles was examined using a steady state, non-linear, computer simulation. These were then followed by field tests using instrumented tie plates. The results of both studies indicated that a conformal profile should significantly reduce wear when compared to the standard AAR profile.

Field tests followed, with a 50 car fleet outfitted with CN Profile "A" wheels. Results of these tests indicated that flange wear could be reduced from 15 to 25% with the conformal profile. Similar savings in the tread area were not observed. The savings are primarily due to greatly reducing the breaking-in period with the AAR profile, when wear is rapid.

Stability tests were conducted with four profiles, new and service worn AAR WF wheels, and experimental Profile "A" wheels, both WF and NF. The results showed a marked deterioration in hunting critical speed with wear (from 60 mph +, to 45-50 mph). The worn AAR profile, and both Profile "A"s were comparable in performance.

The method of measuring wheel profiles using the CN profilometer is described, and some typical profile wear patterns for AAR and Profile "A" wheels are presented. The parallel wear pattern of the Profile "A" wheel, and the tendency of the AAR profile to change markedly with shape are evident.

One of the conclusions is the observation that there is a need to re-examine accepted AAR wheel condemning criteria:

Information of Value to the Wheel/Rail Interaction Program

1. It is again reaffirmed that the hunting behavior of rail vehicles with conformal profiles is no worse than that of service worn AAR profiles. Thus the choice for the vehicle designer remains the same, design vehicles to remain stable with conformal profiles, or maintain tapered profiles through frequent returning.

2. The CN experience was that wide and narrow flange, Profile "A", wheels had similar dynamic performance and similar critical speeds. The effect of flange clearance on stability is one of the variables that will be examined in the analytical portion of this program.

3. The wheel wear saving came from flange wear reductions, not tread wear reductions. Contrary to this, on all LRC locomotive truck wheel profiles measured to date, there has been no appreciable flange wear at all. The first level conclusion to this is that it probably makes no difference to wheel life what profile is used, as wheel tread wear, and other types of wheel damage, will determine the re-machining intervals. If there was a problem of instability with wear, the AAR profile would "buy-time" as it would take longer to achieve the critical levels of effective conicity.

4. The simplifying assumption is made that spin creep effects are cancelled by gravitational stiffness effects. As the gravitational stiffness is known to be an important stabilizing effect, the effect of doing this will have to be examined closely during the calibration phase of the DYNSIM model.

Sect. 4.1.9.

Wheel/Rail Interaction Study.

Literature Review Report.
Paper No. 9.

Title — Influence of Non-Linear Wheel/Rail Contact Geometry on Stability of Rail Vehicles.

Authors — R. Hull
N.K. Cooperrider
Arizona State University.

Publication — A.S.M.E. Paper No. 76 WA/RT-2.

Summary

The paper describes the results of a stability investigation for 3-piece freight car trucks using linearized describing functions to represent non-linearities such as wheel/rail geometry, suspension stops, and dry friction.

Various wheelset constraint functions are established for a standard new AAR wheel, a CN, Profile "A" wheel, and a Heumann profile. The Heumann profile is one developed by Eck and Berg. It is not known how similar it is to the CN Modified Heumann profile. The effective conicities varied considerably over the linear range of lateral motion before flange contact. The profile "A" effective conicity is nearly three times that for the new AAR profile, and for the Heumann profile it is five times that for the AAR profile.

The equations of motion for a 9 degree-of-freedom model of a freight car and two trucks are developed, and all equations given.

The results are given in terms of amplitude of oscillation versus speed for the three profiles. Some interesting concepts concerning the initial destabilizing effects of dry friction are discussed.

Information of Value to the Wheel/Rail Interaction Program

The paper is highly theoretical, and does not refer to actual field testing. There are, however, several observations of interest to the analytical portion of this program.

1. The importance of modelling the non-linear wheel/rail geometric constraints in stability analysis is underlined. (The DYNSIM program does this).

2. It was noted that rear truck dynamic behavior was worse than that for the front truck. This is a field observation from the LRC testing. It may be possible to reproduce this effect, and explain its origins, during the analytical phase of the program.

Sect. 4.1.10

Wheel/Rail Interaction Program.

Literature Review Report
Paper No. 10.

Title — New Tyre Profiles for British Railways.

Author — B. L. King
British Railways

Publication — Railway Gazette, January 19, 1968.

Summary

This paper is somewhat dated (circa 1968) but is interesting as another example of early recognition of the importance of designing vehicles to run stably on worn, or conformal, profiles.

The development of four new profiles, all with the potential of increasing tyre life between turnings, to suit various BR requirements is described.

It is noted that BR nominal gauge was changed from 56.500 ins to 56.375 ins in 1964. It is not known by the author of this literature survey if this practice has been continued.

Some interesting information regarding wheelset back-to-back dimensions and flangeway clearance is given. It is, however, complicated by the use of check rails on British Railways.

Information of Use to the Wheel/Rail Interaction Program

Effective conicities are calculated for several combinations of wheel and rail profiles. One of these indicates high effective conicity for a worn or conformal, profile on new rails. This is consistent with the LRC field experience that instability was often associated with new rail. The data shows, however, that the effective conicity is very high for small lateral motions, and reduces with larger amplitude motions. This has not, to date, been noticed in the field.

2. Gauge and clearance data given is shown below:

track gauge	pre 1964	56.500 ins
	post 1964	56.375 ins
wheelset back to back		53.625 ins
	or	53.540 ins
flange thicknesses (scaled dimensions)	1.06 ins (with 53.625)	
	1.1⁹ ins (with 53.540)	

nominal flangeway clearance (total)

pre 1964 gauge	0.580 ins to 0.755 ins.
post 1964 gauge	0.455 ins to 0.630 ins.

APPENDIX IV

Interim Report #3

Wheel and Rail Profile Measurements

and

Effective Conicity and Contact Angle Development

LRC WHEEL/RAIL INTERACTION

& SUSPENSION STUDY PROGRAM

Interim Report #3

Wheel and Rail Profile Measurements

and

Effective Conicity and Contact Angle Development

Prepared by : David D. Taylor,
David D. Taylor & Associates Inc.

Approved by : R.S. Bergner,
Director of Locomotive Engineering,
Bombardier Inc.,
Rail and Diesel Products Division.

September 1,1986.

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Appendices

A. Definition of Effective Conicity

B. Gauge Variation at Rail Measurement Sites

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1.0 Introduction

Unexpected truck instability problems had arisen with the Via Rail LRC Locomotives when they were first placed into service in 1983. The problems were related to the introduction of a different wheel profile to that used on the prototype LRC locomotive, and on the Amtrak LRC locomotives. It had become apparent during the process of resolving these problems that not enough was know about the actual wheel/rail interaction geometry and its effect on vehicle stability.

This program, sponsored by The Transportation Development Centre of Transport Canada, was intended to increase understanding in this area by extending the scope of the efforts to resolve these problems that were ongoing at that time. It was approved in the fall of 1984, and became active in the spring of 1985. Under its auspices, wheel and rail measurements were taken and processed, a suspension modification tested and a theoretical analysis program undertaken. The rail measurements were taken at two sites, known to be conducive to stable and unstable vehicle behavior respectively. The wheel measurements were taken on two LRC locomotives at observed and recorded changes of dynamic performance of the locomotives. In one case, this constituted a change from stable to marginally unstable behavior with increasing mileage on the wheelsets while in the other, a change from unstable to stable behavior was recorded and attributed to a suspension modification.

The wheel and rail profile data was measured and processed by CN Research to produce graphs of change in wheelset rolling radius and contact angle with lateral motion of the wheelset, for the various combinations of wheel and rail profiles recorded. The subsequent averaging of the individual wheelset and rail interaction data to establish input values for the computer analysis was done by Bombardier. The rail site and wheelset mileage selections were also done by Bombardier. This Interim Report describes the development of the data, tables the averaged results, and discusses some of the findings obtained. The data should be of interest in its own right, and was used as input to the DYNSIM computer program in the theoretical analysis portion of this program.

The data is presented in a form suitable for inclusion in the computer program, rather than as effective conicity. The procedure for calculating the effective conicity from this data is given in Appendix A

2.0 Measurements of Wheel and Rail Profiles

2.1 Technique

The wheel and rail profiles were measured by the CN Research Department, using their specially designed profilometer. This device is clamped to the wheel or rail, and measures and records the profile electronically in digital form by means of a follower and screw advancing mechanism. Readings are typically taken every 0.005 inches. In the case of the wheel readings, locating holes are drilled in the wheel rim to insure accurate re-positioning of the device for repeat readings. The data points are referenced with respect to gravity by means of a clinometer which is placed on the machined top surface of the device. The wheelset back-to-back dimension and the the wheel diameters are measured separately. Photographs of the profilometer and clinometer are shown in Figs.1 and 2.

The wheel and rail profiles are then combined, using computer software developed by CN Research. The process is one of mathematically placing the wheelset on the rails at the nominal center position and with various amounts of lateral offset, calculating the rolling radius and contact angles for each wheel at each position. The change in rolling radii and the change in contact angle for each wheelset is then plotted versus lateral offset.

2.2 Rail Measurements

2.2.1 Site Selection

During the course of the LRC testing program it was frequently apparent that the instability, or hunting, was sensitive to the rail conditions. The general tendancy was that newly laid rail promoted instability, although the exact reason for this was not allways clear. For the purposes of this study, two rail sites were selected. The first, at MP 77.5, Kingston Subdivision, CN Rail, was representative of rail where the vehicle performance was allways stable, under all test conditions. The second, at MP 165.56, Kingston Subdivision, was at the location where hunting was found to have recommenced on test locomotive, LRC Unit 6930, in August, 1985 (see Interim Report #1).

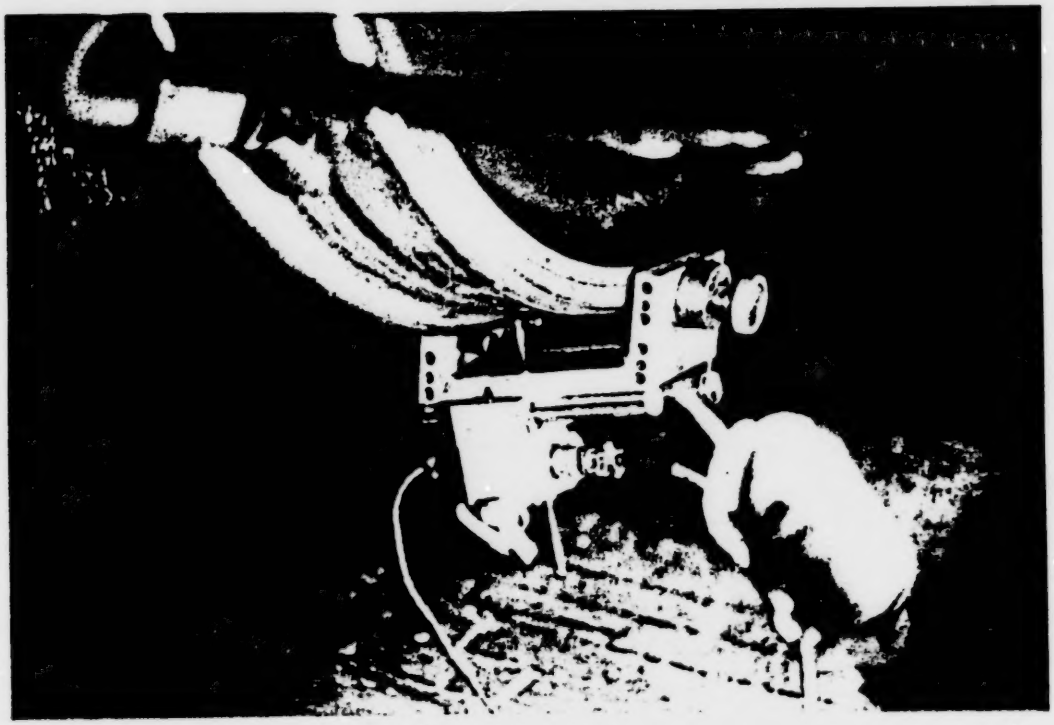


Fig. 1 CN Profilometer

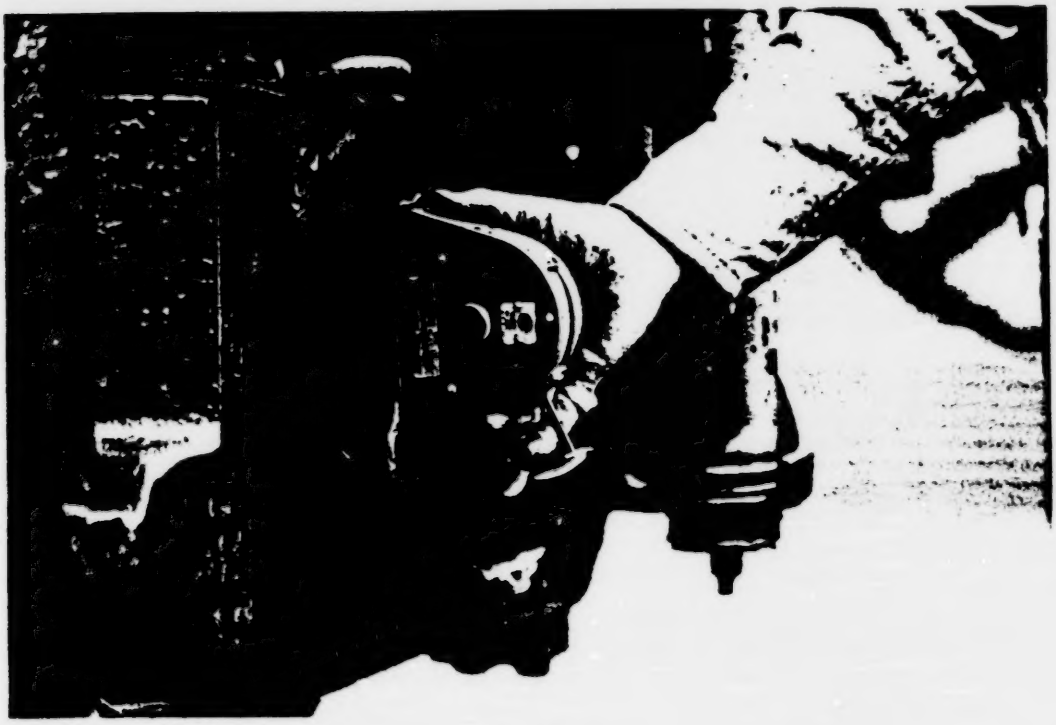


Fig. 2 CN Clinometer

2.2.2 Site Data

Profile measurements were taken at two sites by CN Research, as follows;

Measurement Site MP (Kingston Subdivision)	77.5	165.56
Reason for Selection	stability of test locos	instability of test locos
Date	Dec.10,1985	Oct.28,1985
Track	North	North
Rail		
Manufacturer	Sydney, 132 RE	Algoma, 132 RE
Date of manufacture	Oct.,1982	
Date of installation		June-July, 1985
Location	tangent	tangent
Gauge at measurement site	56.50 ins.	56.50 ins.
Ties	wooden	wooden
Tie plates		14 ins. 2 spikes/plate
Rail anchors		every second tie

2.2.3 Observations

Gauge Variation

The gauge was measured at several sites near the actual profile measurement locations using a gauge bar. Some random gauge variation was found. The data points and a graphical representation of the data are shown in Appendix B. The gauge at the actual measurement sites was nominal (56.50 ins.).

Rail Surface

There was a marked difference in the appearance of the shiney patch on the rail surface at the two measurement sites. At MP 77.5, the shiney patch was about 1/2 inches wide, and was located just outside the rail head centerline. At MP 165.56 the shiney patch covered most of the rail head surface on the north rail, and the inner 60 - 70 % of the surface on the south rail. On both rails it extended right into the gauge face area. This matter will be explored further in Sect.4.

2.3 Wheel Measurements

2.3.1 Measurement Mileage Selection

Unit 6925 was assigned to the test program by Via Rail. It had its wheelsets machined to the CN Modified Heumann profile, and was released into revenue service on August 8, 1985,with no modifications to the truck suspension. Based upon past experience, it was expected that this unit would have an initial period of stable operation, followed by the onset of instability as the profile changed with wear. At this point the primary suspension chevrons would have been replaced with chevrons stiffer in the longitudinal direction, and a non-revenue road test conducted. The CN Research crew took a complete set of wheel profiles at zero mileage, and at the initial onset of instability, which occurred after approximately 40,000 miles of service. Because of delays in arrangeing to take the measurements, the profiles were actually taken after 50,000 miles of service.

Unit 6930 was included in this test program when it began to hunt again in August, 1985. This unit had the new Koni yaw dampers applied, and it was hoped that it represented a final technical solution to the hunting problem. When the hunting recommenced, after 46,000 miles of service, the new chevrons intended for Unit 6925 were applied to Unit 6930. The unit was then successfully tested for stability at speeds of up to 103 mph in September, 1985 (see Interim Report #1). The CN Research crew measured the wheel profiles of this locomotive at about 66,000 miles. It was not possible to arrange the measurements at closer to the 46,000 miles that it was intended to capture. The profiles at 46,000 miles were interpolated using the CN data at 66,000 miles and pencil trace type measurements taken by Bombardier at 46000 and at 66,000 miles. The mileage on Unit 6930 included a simulated 30,000 miles of wear machined onto the wheels using a specially designed template based upon pencil trace readings of the wheelsets taken previously. This was done to salvage the test program after an unscheduled wheel machining, and is described in more detail in Interim Report #1.

2.3.2 Wheel Measurements

The following wheel profile measurements were taken by CN Research;

Locomotive	6925	6930
Suspension configuration	conventional	new yaw dampers & (after Sept.23,1986) new chevrons
Measurements		
#1 date	Aug.8,1985	Jan.20,1986
mileage	0	66,000
#2 date	Dec.6,1985	-
mileage	50,000	
Interpolated	-	
date		Aug.29,1985
mileage		46,000

3.0 Rolling Radius and Contact Angle Variation with Lateral Offset (Data Prepared by the CN Research Department)

3.1 Sample Result

Fig. 3 illustrates a sample of the data generated by the CN Research Department from the rail and wheel profiles measured. The sample selected is LRC 1, and applies to the #1 axle of locomotive Unit 6925 at 0 mileage, at rail location MP 77.5. Lateral position refers to the lateral offset of the wheelset with respect to the nominal track centerline. RDIF and FNLT refer to the rolling radius difference and the contact angle difference between the two wheels at that lateral position. The relatively flat region in the center applies to the flangeway clearance area before the flange is contacted. The steeper slopes at the ends indicate that flange contact has occurred. The line of demarcation between the two areas is not always as clearly defined as it is in this example.

A more detailed explanation of the data given in the figure is included in the CN report. This report will be included in the Final Report for the Wheel/Rail Interaction Project.

3.2 Tabulated Results

Thirty-nine sets of similar data are included in the CN report. They are catagorized as follows;

i) LRC 1 to LRC 32

- 2 locomotives x 2 sets of wheel profile readings loco x 2 sets of rail profile readings x 4 axles/loco

= 32 data sets

ii) LRC 33 to LRC 35

- several combinations of theoretical and actual wheel and rail profiles.

iii) LRC 36 & LRC 37

- effect of rail cant variation for a typical data sample

iv) LRC 38 & LRC 39

- effect of rail gauge variation for a typical data sample

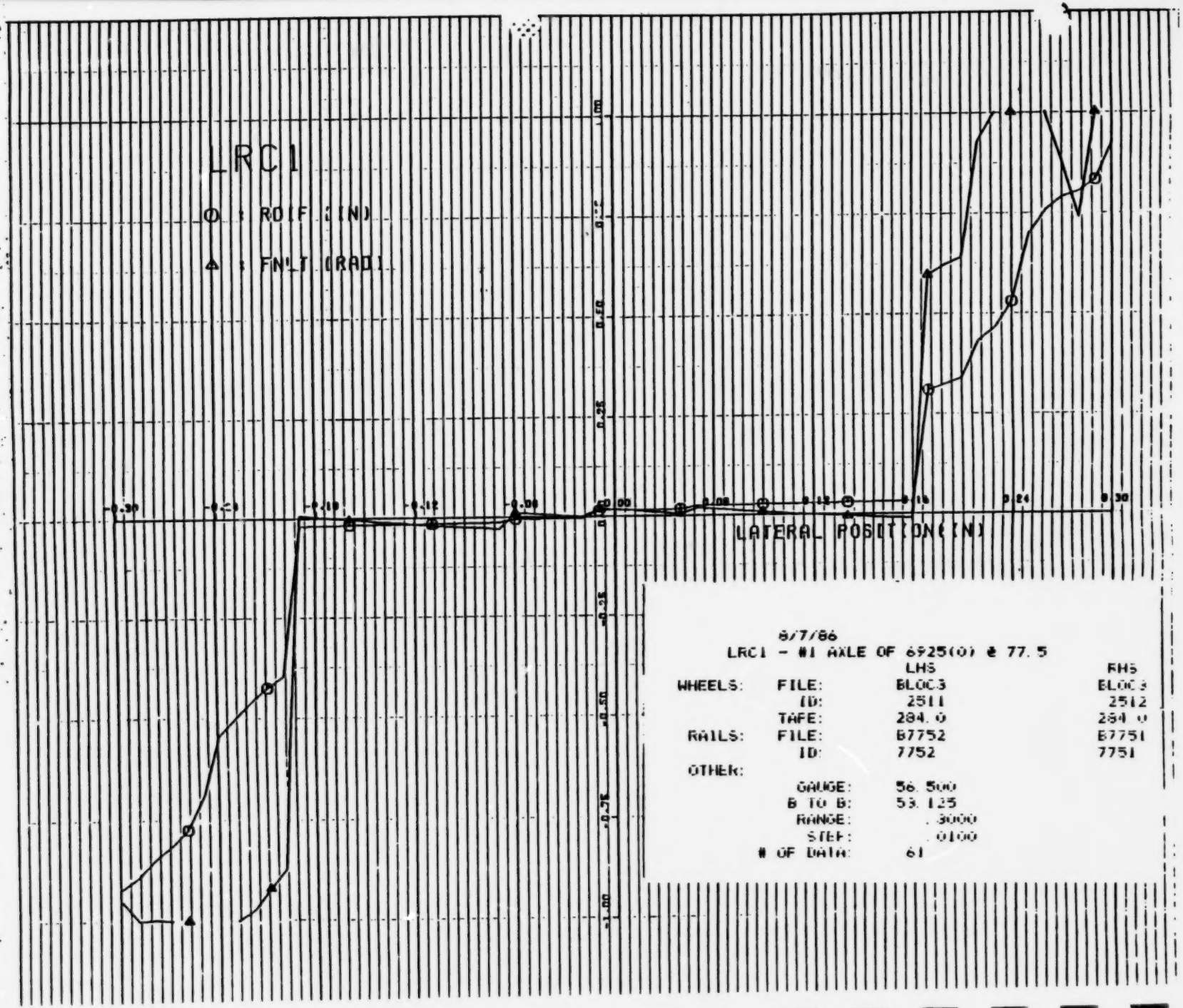

LRC1
O : ROLF (IN)
Δ : FNLT (RAD)
LATERAL POSITION(IN)
8/7/86
LRC1 - #1 AXLE OF 6925(0) @ 77.5
LHS
RHS
WHEELS: FILE: BLOC3 BLOC3
ID: 2511 2512
TAPE: 284.0 284.0
RAILS: FILE: B7752 B7751
ID: 7752 7751
OTHER:
GAUGE: 56.500
B TO B: 53.125
RANGE: .3000
STEP: .0100
OF DATA: 61

FIGURE 3

4.0 Averaged Results

The averaged values for several combinations of wheelsets and rail sites were developed by Bombardier to produce the values used as input for the computer analysis portion of the program. A simple mathematical averaging procedure was used to establish the averages.

4.1 Averaged Data - All Wheelsets

Fig. 4 illustrates the average change in rolling radius for the two locomotives at the two different mileage conditions, at MP 77.5.

Fig. 5 illustrates the average change in rolling radius for the two locomotives at the two different mileage conditions, at MP 165.56.

Fig. 6 illustrates the average change in rolling radius for Unit 6930 at MP 165.56, with the leading and trailing truck axles separated. This was done because, with the locomotive in the trailing position, it was found that the cab end truck was hunting while the other truck was stable at this track location. (With the unit in the trailing position, the hunting truck was the last truck in the train consist)

4.2 Test Case Data

In order to validate the computer model, two test cases were prepared, corresponding to the two changes in operating performance referred to earlier in this report.

Test Case #1 considers the change in performance in Unit 6925 between 0 and 50,000 miles. This Unit was released into revenue service with no modifications to the suspension and using the CN Modified Heumann Profile. It was monitored for stability periodically, and began to show signs of instability after 50,000 miles. The data used in the modeling of this performance change is shown in Fig. 7.

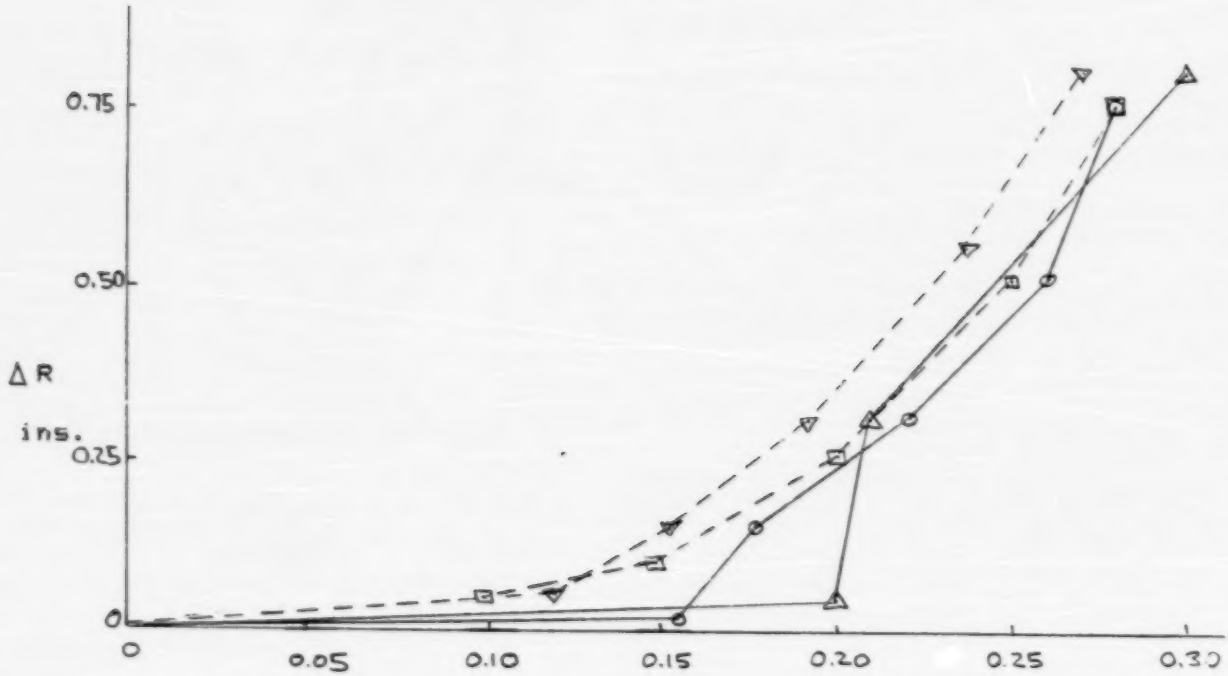
Test Case #2 considers the change in performance in Unit 6930 after 46,000 miles of wear, at MP 165.56, due to a change in suspension. This unit was hunting at this site, and was stabilized by increasing the primary suspension longitudinal stiffness from 62,000 lbs./in./journal, to 100,000 lbs./in./journal. The data used in the modeling of this performance change is shown in Fig. 8.

Change in Rolling Radius

Average for All Wheelsets

LRC Units 6925 & 6930

MP 77.5



Legend	Unit	Axles	Mileage	MP
△	6925	all	0	77.5
⊙	6925	all	50,000	77.5
⊡	6930	all	46,000	77.5
▽	6930	all	66,000	77.5

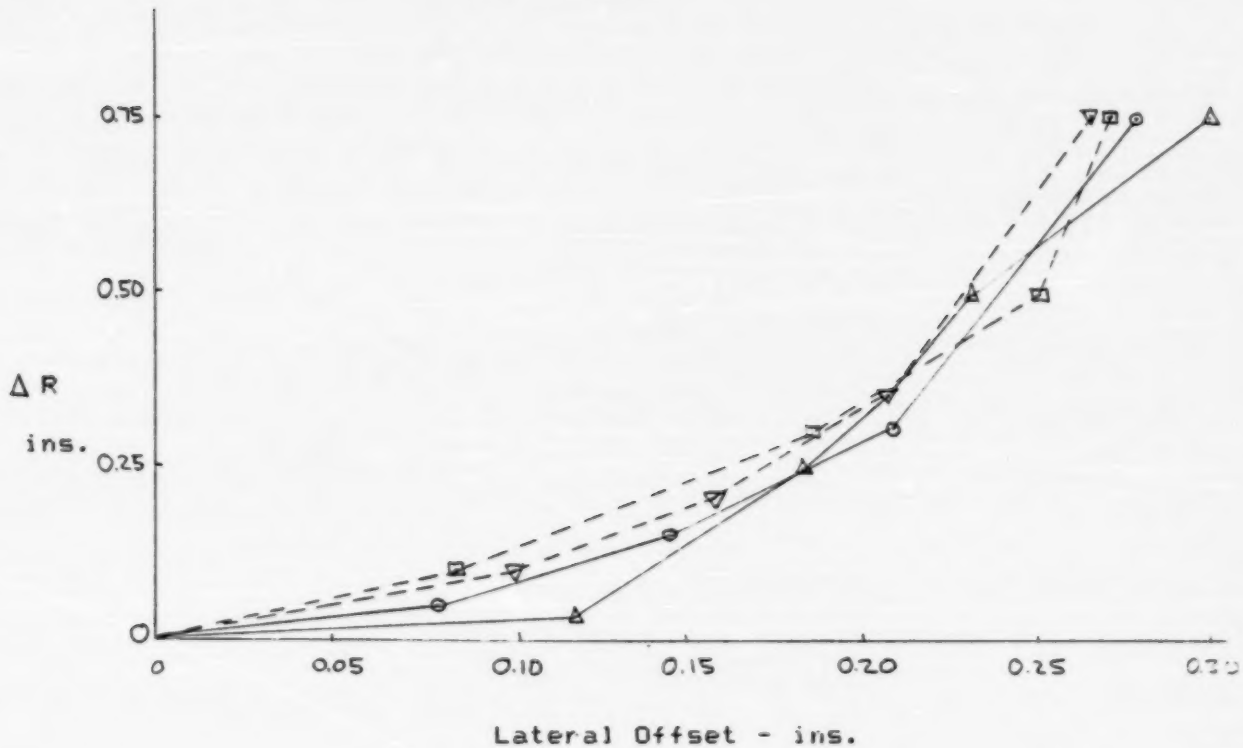
FIG. 4

Change in Rolling Radius

Average for All Wheelsets

LRC Units 6925 & 6930

MP 165.56



Legend	Unit	Axles	Mileage	MP
△	6925	all	0	165.56
⊙	6925	all	50,000	165.56
⊡	6930	all	46,000	165.56
▽	6930	all	66,000	165.56

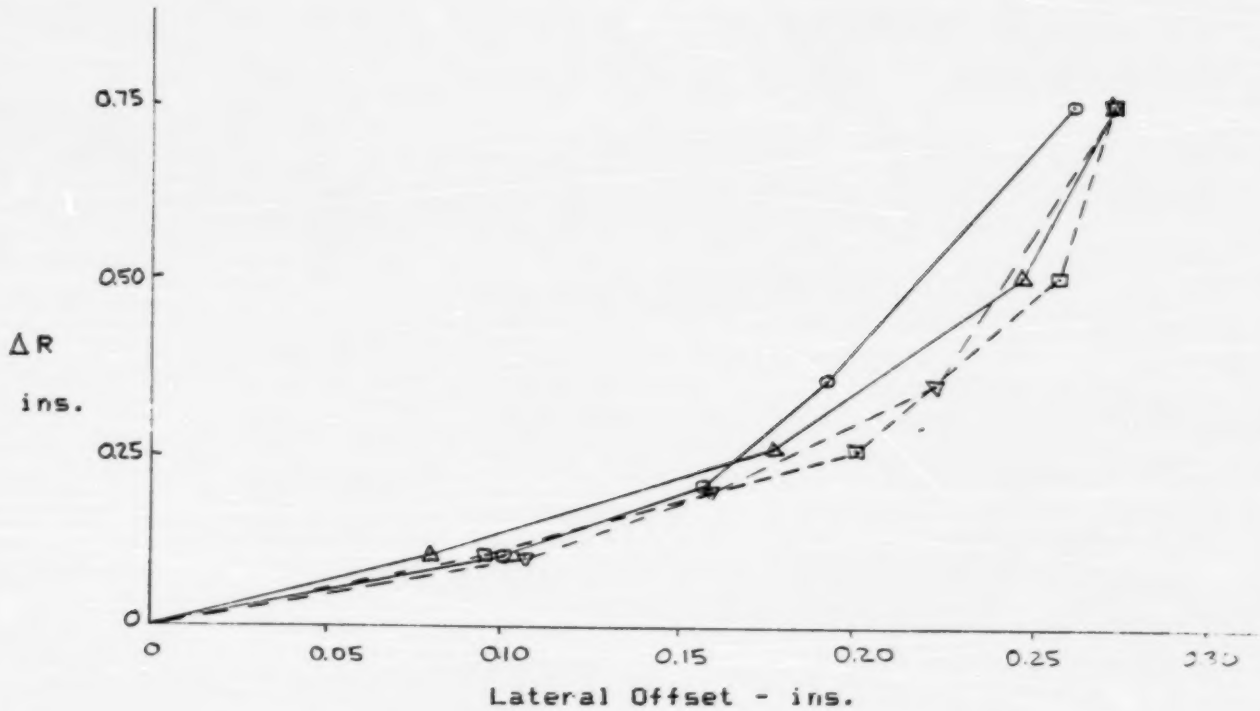
FIG. 5

Change in Rolling Radius

Average for Wheelsets 1&2 and 3&4

LRC Unit 6930

MP 165.56



Legend	Unit	Axles	Mileage	MP
△	6930	1&2	46,000	165.56
⊙	6930	1&2	66,000	165.56
□	6930	3&4	46,000	165.56
▽	6930	3&4	66,000	165.56

FIG. 6

Test Case #1

Unit 6930 @ 46,000 Miles

Axles 1&2

Suspension	MP 77.5	MP 165.56
Dampers Only	stable	unstable
Dampers + Chevrons	stable	stable

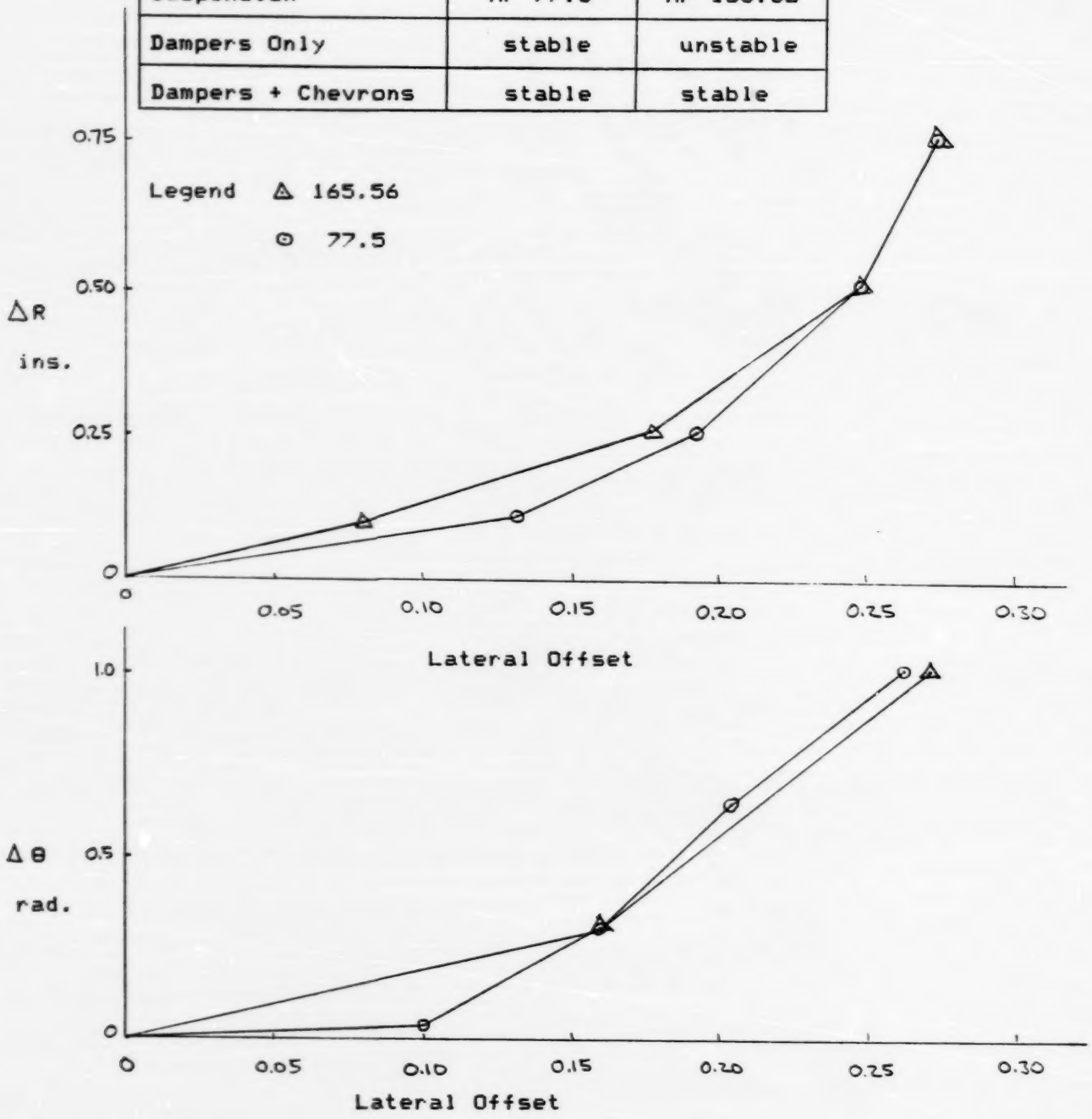


FIG. 7

Test Case #2

Unit 6925 @ 0 and 50,000 Miles

Suspension	0 Miles MP 77.5	50,000 Miles MP 165.56
As Built	stable	marginally unstable

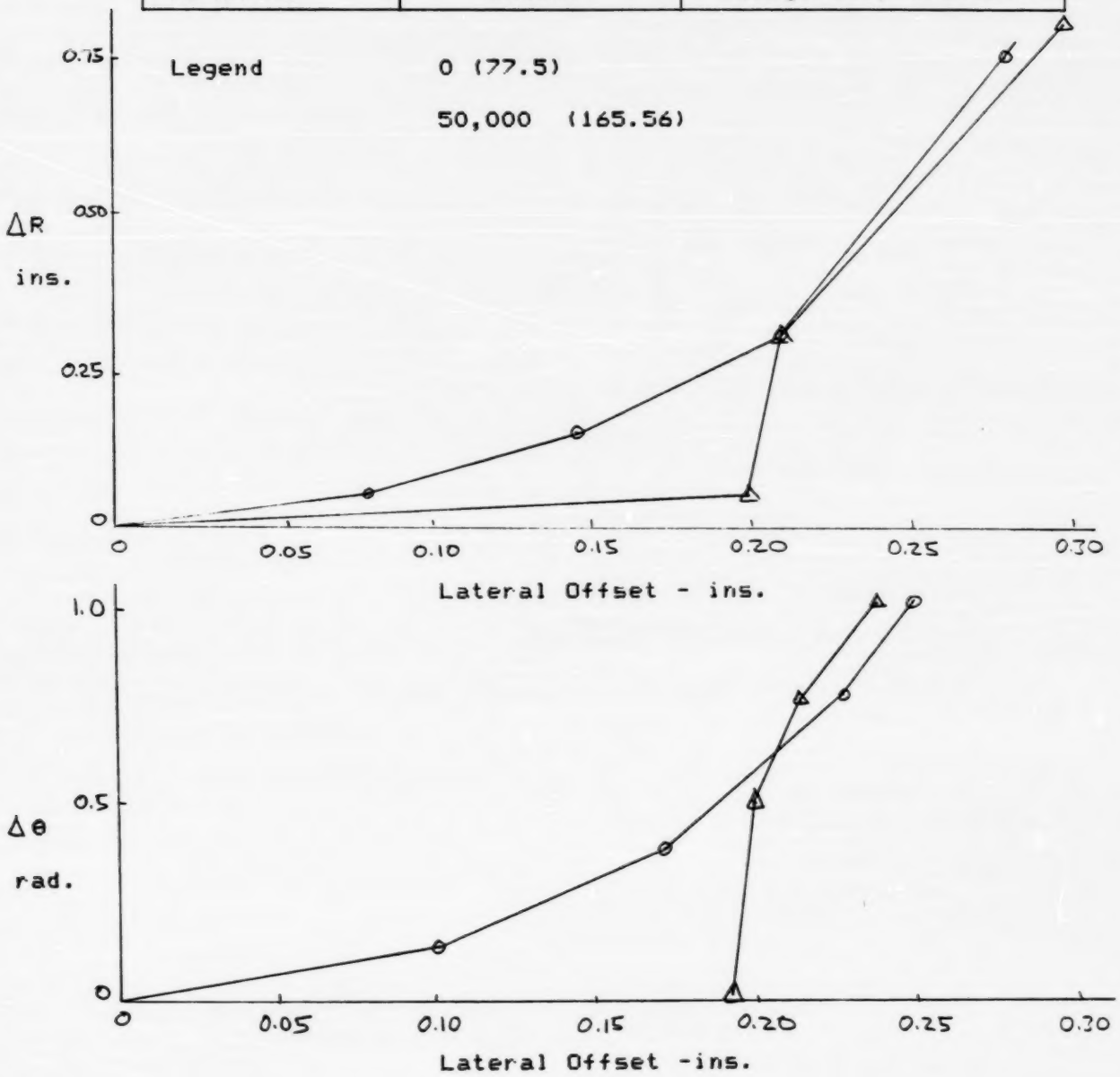


Fig. 8

5.0 Observations / Discussion

5.1 Change in Wheel Profile with Wear

Figs. 9 to 12 illustrate the wear that occurred to the wheelsets of Unit 6925 from 0 to 50,000 miles of service. The profile change and the actual loss of metal across the profile are clearly shown. The metal loss is plotted at 2X scale for clarity.

The changes in rolling radius and contact angle with lateral offset corresponding to this wear are shown for two track locations in Figures, LRC 1 to 8, and LRC 17 to 24, CN Report.

The changes in rolling radii with lateral offset at MP 77.5 are held to be the more representative because of the asymetric results at MP 165.56 (see Sect. 5.2). In the case of wheel R1, the wear has actually lengthened the low conicity area in a way that should be stabilizing. For all other wheels, the wear tended to increase the conicity, and will be destabilizing. The wear is predominantly in the tread area; little flange wear was recorded.

5.2 Asymetric Results at MP 165.56

The change in rolling radius results plotted at MP 165.56 show a rolling radius difference at the zero offset position (see CN Data, LRC 17 to 32). This tendency is most pronounced for Unit 6930, but is also present for Unit 6925. It is not apparent at MP 77.5, for either vehicle.

There is evidence to suggest that the head of the south rail at MP 165.56 is rotated in such a way that it is vertical when the base is canted inwards at 1:40. This possibility will be examined in greater detail in the final report.

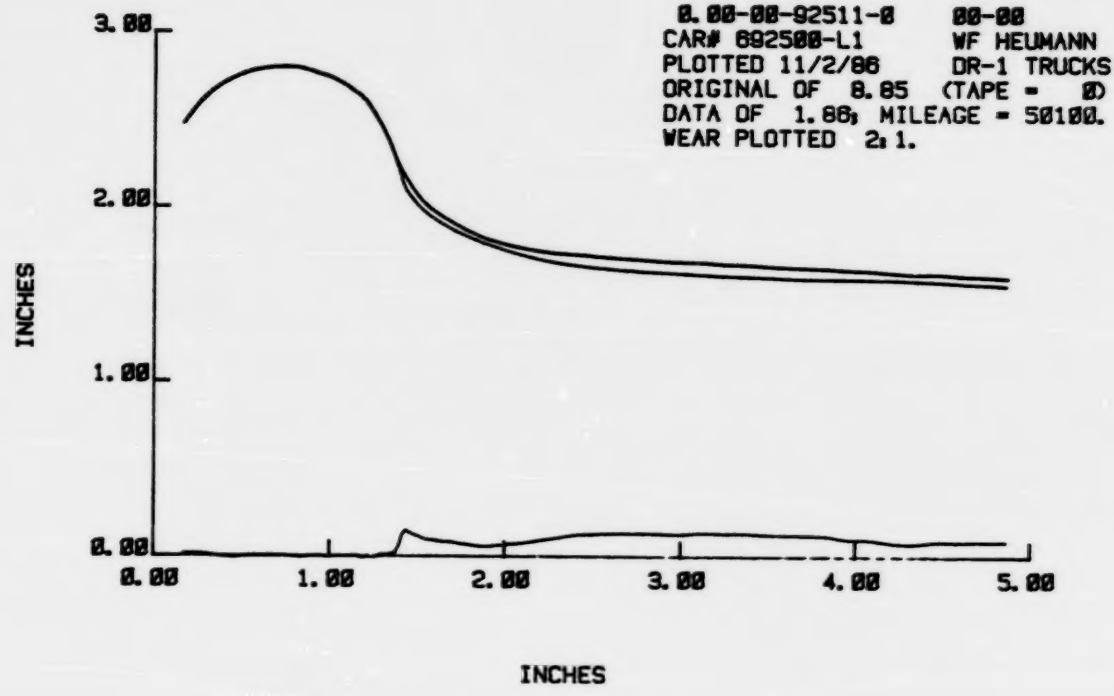
This zero offset condition cannot be modeled in the DYNSIN computer program. The crossing of the "Y" axis by both the RDIF and the FNLT curves has been taken to be the zero for the vertical readings. In this way, the change in rolling radius and contact angle with lateral motion is accurately modeled, but the zero offset is not.

5.3 Results of Theoretical Parameter Variation (CN Data)

5.3.1 Nominal Wheel and Rail Profiles Compared with Actual Profiles

i) LRC 33 Nominal Heumann Profile at MP 77.5

These results are very similar to the actual zero mileage for Unit 6925 at MP 77.5 (LRC 1-4, CN Report). This indicates that the wheel profile is very close to the nominal.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1.00
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INCHES
0.00
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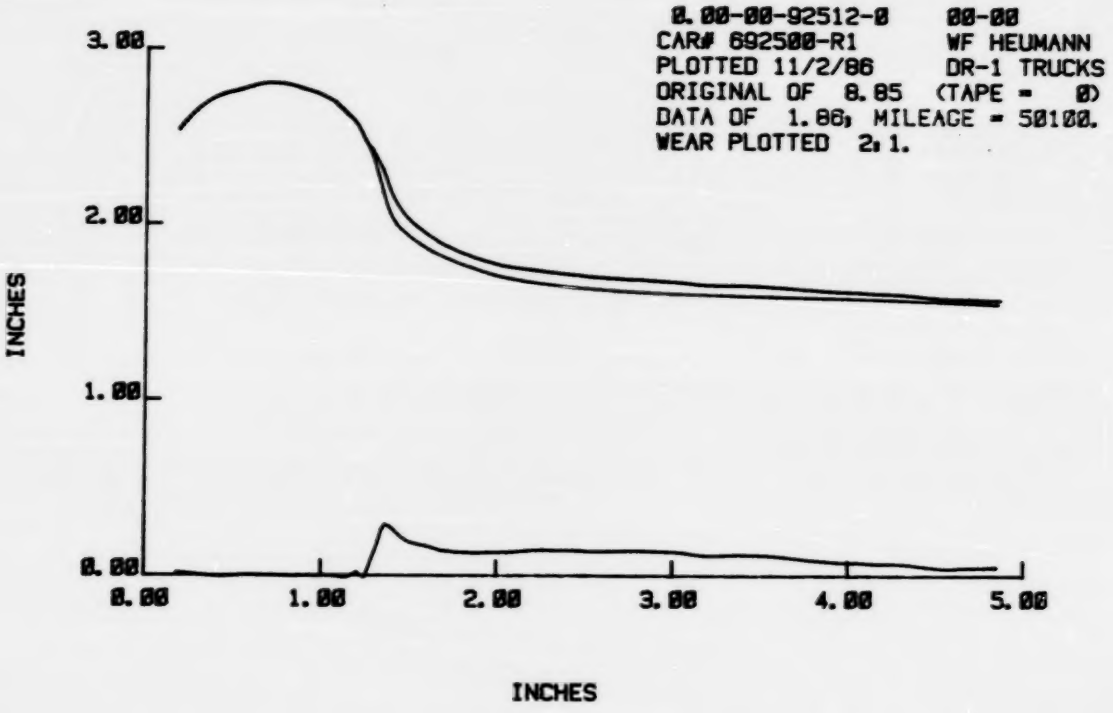
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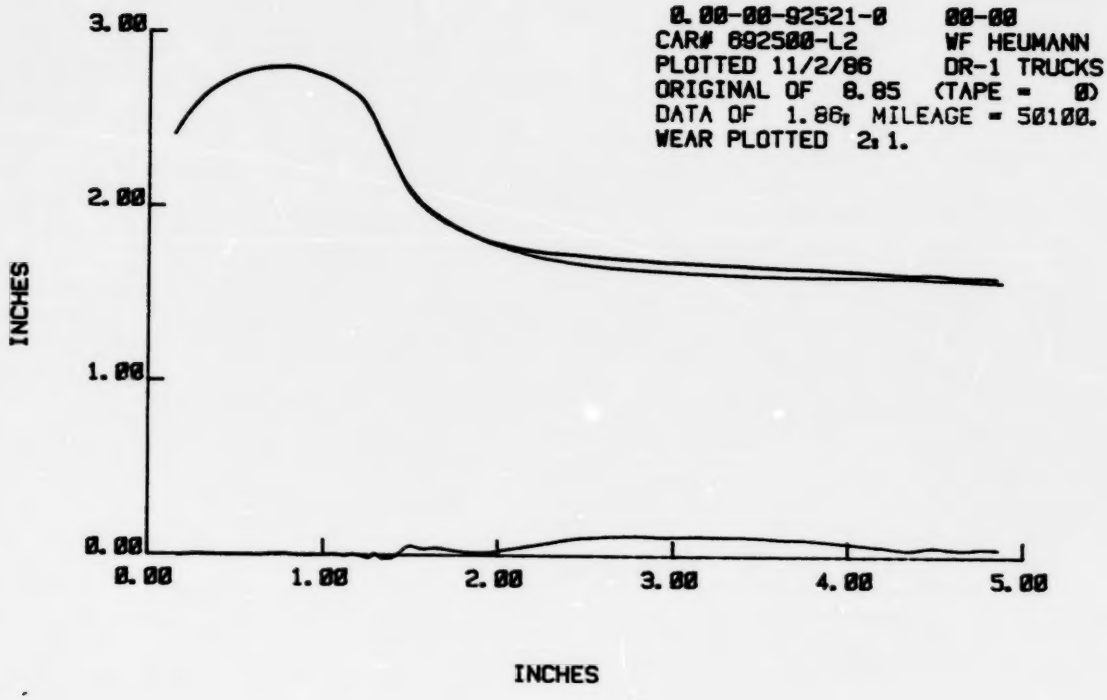
INCHES

FIGURE 9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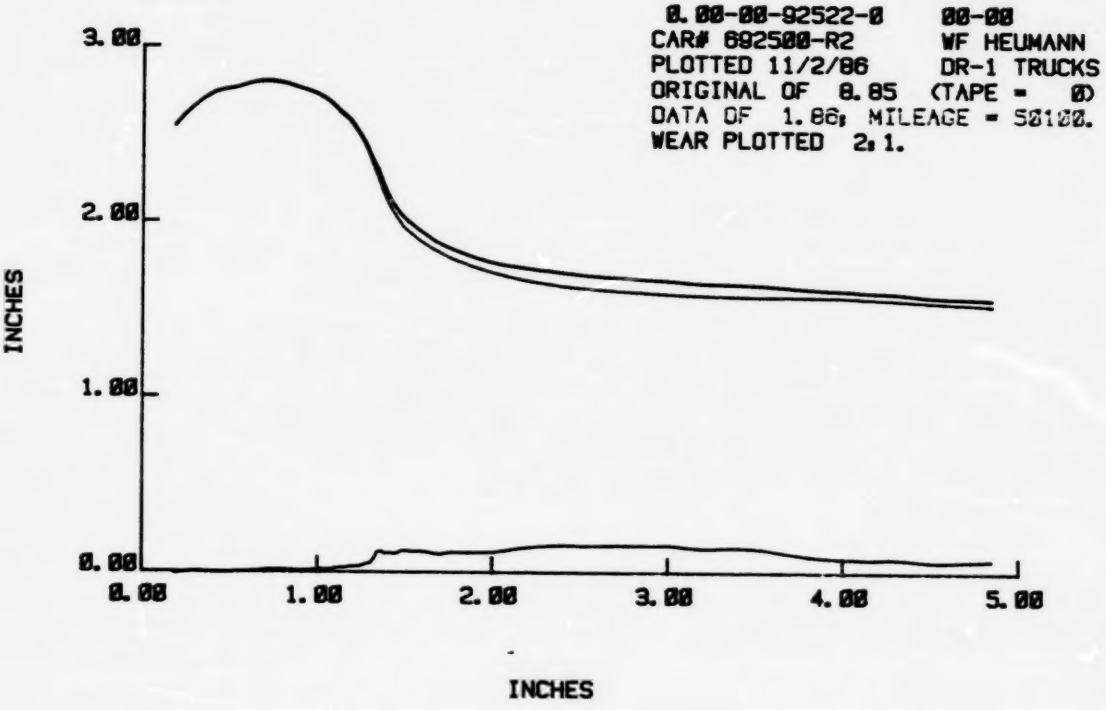
INCHES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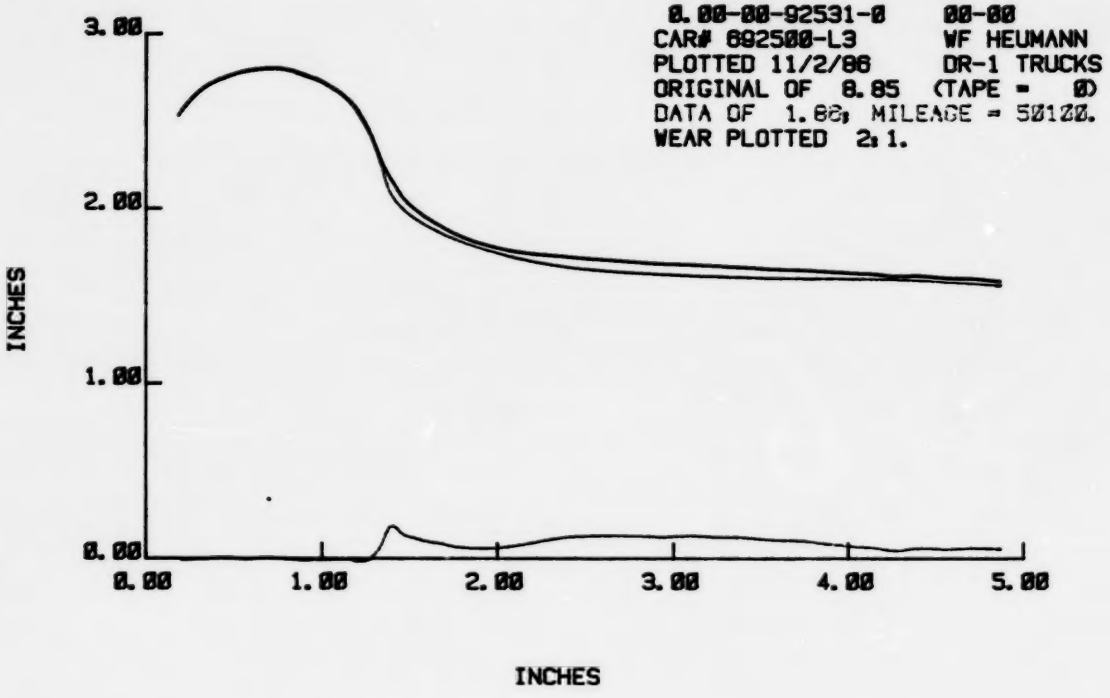
INCHES

FIGURE 10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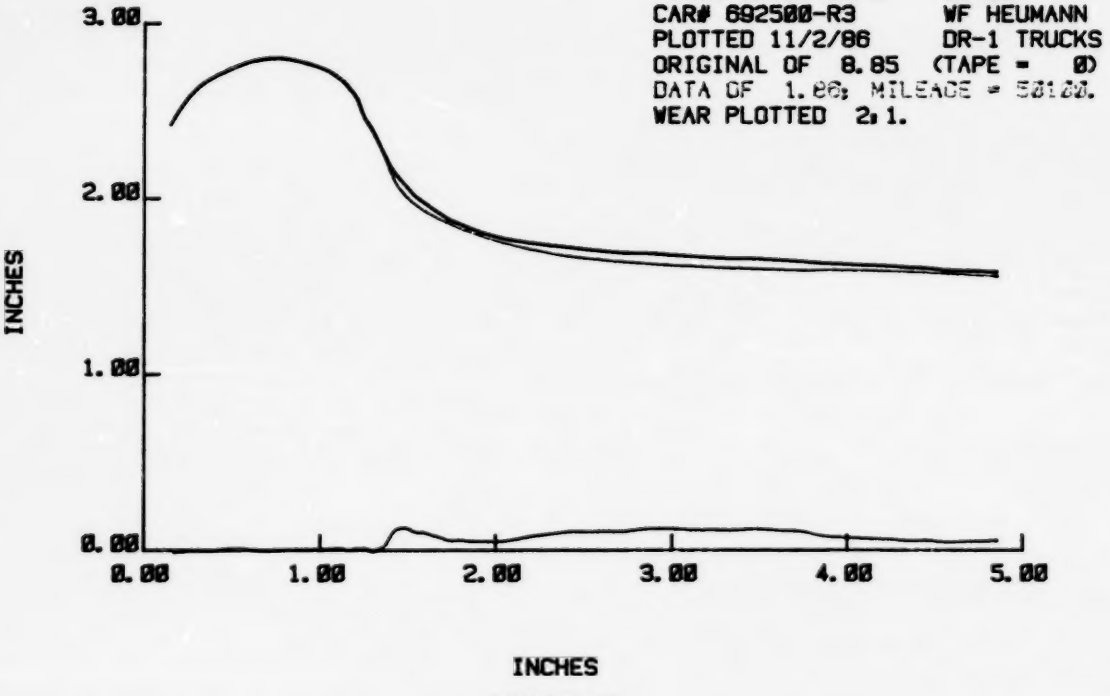
INCHES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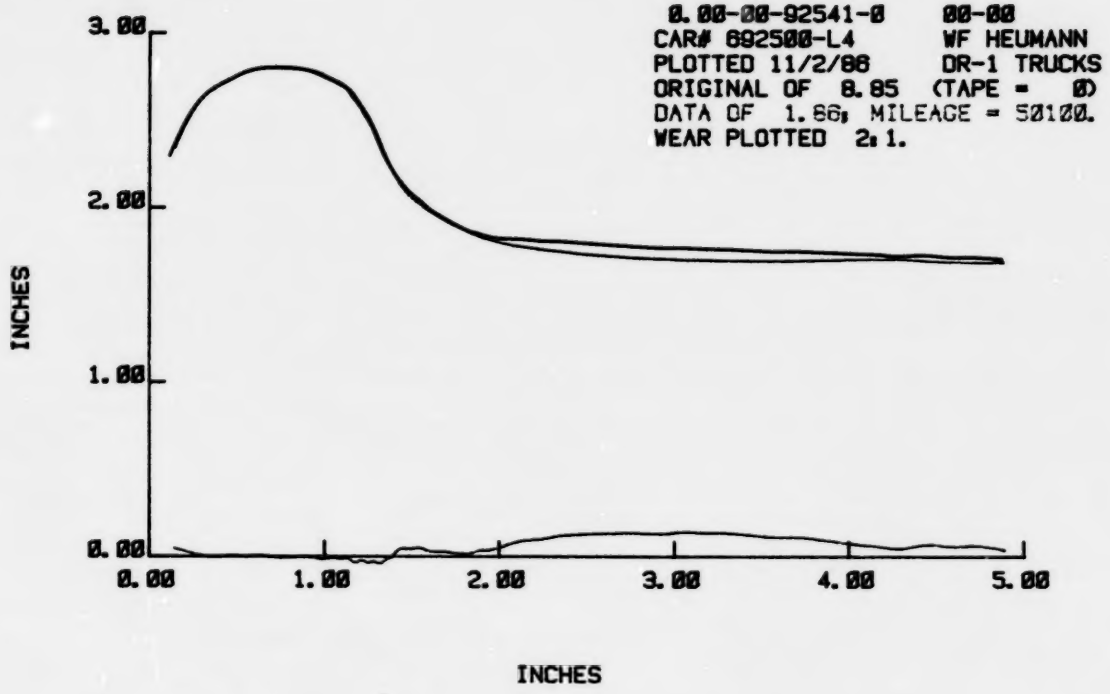
INCHES

FIGURE 11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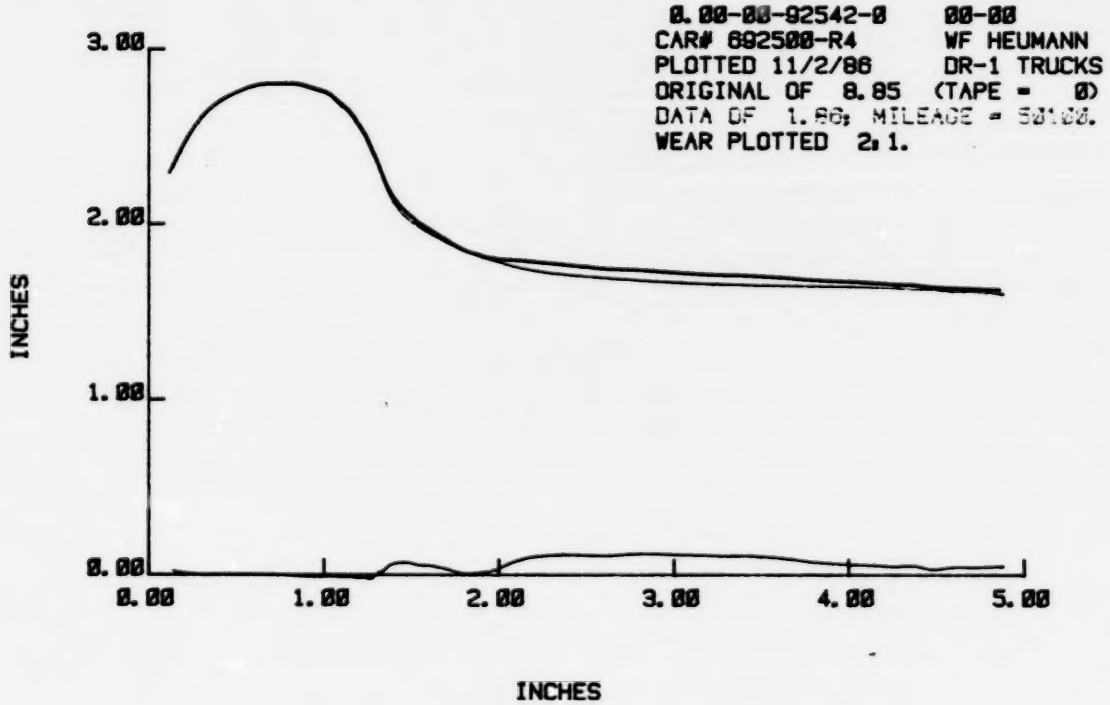
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INCHES
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INCHES

FIGURE 12

ii) LRC 34 Nominal Heumann Profile on Nominal 132 lb. Rail

Compared with LRC 33, the ΔR rises more steeply in the flange root area, and less steeply once the flange has been contacted. This difference is not explained.

iii) LRC 35 #1 Axle, Unit 6925, on Nominal 132 lb. Rail

This result is very similar to that of LRC 34, above, and again indicates that the nominal and actual zero mileage wheelset profiles are very similar.

5.3.2 Effect of Cant Variation

LRC 36 & 37 show the effect of changing the cant angle while maintaining the track gauge, for Unit 6925, axle #1, at 50,000 miles, MP 77.5. Decreasing the cant angle reduces the effective lateral clearance and will, for this reason, be destabilizing.

Nominal 1:40 cant gives an angle of 1.43 degrees to the vertical. If the hypothesis that the rail is near vertical at the south rail, MP 165.56, this gives an angular variation nearly three times that shown in LRC 36. This could have a large effect on the apparent flangeway clearance on that side, and could be responsible for the vertical offset of the zero crossing.

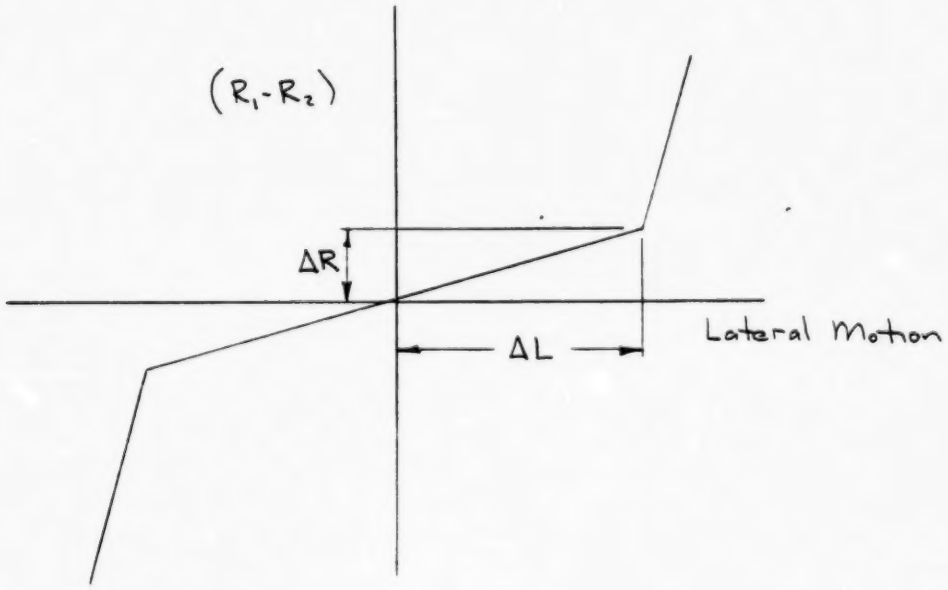
5.3.3 Effect of Gauge Variation

In LRC 38 and LRC 39, the track gauge is varied by plus/minus 0.125 inches.This has a linear effect on the flangeway clearance. It is clear from this data that tight gauge will have a negative effect on flangeway clearance, and hence on stability.

Appendix A

Definition of Effective Conicity

The data presented in this report is plotted in the form of change in rolling radius as a function of lateral motion of the wheelset. It can be readily converted to its effective conicity equivalent by the use of the following formula:



$$\text{Effective Conicity} = \frac{\Delta \text{ Rolling Radii}}{2 * \Delta \text{Lateral Motion}}$$

$$= \frac{\Delta R}{2 * \Delta L}$$

Appendix B

Gauge Variation at Rail Measurement Sites

1. MP 77.7

Distance east of measurement site	Gauge Variation	
ft.	ins.	
0	0	
3	+1/32	
6	0	
9	+1/32	
12	+1/64	
15	0	
18	+1/64	
21	-1/32	
24	+1/16	
27	-1/64	
30	-1/64	
33	0	
36	+1/64	
39	+1/64	
42	+1/16	
45	+1/32	
48	0	
51	0	
54	+1/16	
57	+1/16	
60	+1/8	
63	+1/8	
66	+3/16	
69	+1/32	
72	0	
75	0	
78	+1/32	
81	+1/32	
84	0	
87	0	
90	0	
93	+1/4	(rail joint)
96	+1/16	

2. MP 165.56

0	0
30	+1/32

36	-1/8 +
50	0
80	-1/16
90	0
110	-1/8 +
120	0
130	0
140	-1/8
145	0

3. MP 165.1 (This data was taken in a curve near the measurement site and is included here as a matter of record)

0	+1/8
50	-1/16
100	+1/16 +
125	+1/8
150	+3/16
200	0
250	+1/16
275	0
300	+1/16
350	+1/16
375	+1/8
400	+1/8
450	+1/16
475	+1/8
500	0
550	+1/8
575	0
600	+1/16
650	+1/16
675	0
700	+3/16
735	+3/16
767	+1/16

APPENDIX V

LRC Locomotive

Basic Truck and Suspension Parameters

Appendix V

LRC Locomotive

Basic Truck & Suspension Parameters

Parameter		Original Via Suspension	"1983" Suspension	1986 Modified Suspension
Wheel Data				
Profile		CN Modified Heumann WF	AAR 1:40 WF	CN Modified Heumann WF
Back-to-back	ins	53.125	53.125	53.125
	(mm)	(1349)	(1349)	(1349)
Nominal Flangeway Clearance/Side	ins	0.313	0.313	0.313
	(mm)	(7.9)	(7.9)	(7.9)
Weights				
Total Weight on Rail	lbs	-	254,000	-
	(kg)	-	(115,214)	-
Truck Weight	lbs	-	38,000	-
	(kg)	-	(17,237)	-
Suspension Data				
Primary Suspension Rates				
Longitudinal				
lbs/in/journal		63,000	63,000	63,000
(kN/mm/journal)		(11.03)	(11.03)	(11.03)
Lateral				
lbs/in/axle		33,000	33,000	33,000
(kN/mm/axle)		(5.75)	(5.75)	(5.75)
Vertical				
lbs/in/journal		7,825	7,825	7,825
(kN/mm/journal)		(1.37)	(1.37)	(1.37)
Vertical Damping				
lbs-sec/in/journal		195	260	260
(N-sec/m/journal)		(34,150)	(45,533)	(45,533)

Secondary Suspension Rates

Lateral - before bump stop			
lbs/in/truck	1,800	1,800	1,800
(kN/mm/truck)	(0.315)	(0.315)	(0.315)
Vertical			
lbs/in/truck	15,150	15,150	15.150
(kN/mm/truck)	(2.65)	(2.65)	(2.65)
Lateral Damping			
lbs-sec/in/truck	490	490	490
(N-sec/m/truck)	(85,811)	(85,811)	(85,811)
Vertical Damping			
lbs-sec/in/truck	910	910	910
(N-sec/m/truck)	(159,365)	(159,365)	(159,365)
Yaw Damping (2 dampers, 72 in centers)			
lbs/damper	2,200	2,800	5,000
(N/damper)	(9.786)	(12,455)	(22,241)

APPENDIX VI

SPEC Documentation

of

Work Sessions

LRC Wheel/Rail Interaction and Suspension Program

Bombardier/TDC

Session of March 19, 1985

SPEC DOCUMENTATION
OF
WORK SESSIONS

LRC WHEEL/RAIL INTERACTION & SUSPENSION PROGRAM
BOMBARDIER/TDC
SESSION OF MARCH 19, 1985

MANAGEMENT SYSTEMS
DIVISION, CPCS

MARCH 25, 1985 (REVISION #1)

MARCH 20, 1985

PROJECT # 0007

SPEC INFORMATION BASE

LRC WHEEL/RAIL INTERACTION & SUSPENSION PROGRAM

BOMBARDIER/TDC

SESSION OF MARCH 19, 1985

MANAGEMENT SYSTEMS
DIVISION, CPCS

MARCH 25, 1985 (REVISION #1)
MARCH 20, 1985
85-0007-A01
RWG/BT/LM

THIS OUTPUT IS A DOCUMENTATION OF THE FACTS, IDEAS, AND DECISIONS THAT HAVE BEEN DEVELOPED BY THE PARTICIPANTS DURING A SPEC WORK SESSION. THIS IS A REPLICA OF THE "MEMORY TRACE" CREATED ON THE WALLS OF THE MEETING ROOM DURING THE SESSION.

PARTICIPANTS

R.S. BERGNER

N. CALDWELL

W.H. EL MARAGHY

D. TAYLOR

B. MARSHALL

C. FONTA

S. VESPA

B. YOUNG

MODERATORS

ROY GILLETT

BENOIT TRUDEAU

PURPOSE OF THE SESSION

TO PLAN LRC WHEEL/RAIL INTERACTION AND SUSPENSION STUDY PROGRAM

BACKGROUND

PROBLEM

LRC LOCO TRUCKS HUNTING IN OPERATING SPEED RANGE

- TASK FORCE ESTABLISHED TO MONITOR ACTIVITY

TEMPORARY MEASURE

LOCOS NOW RUNNING ON AAR 1:40 PROFILE RATHER THAN MODIFIED HEUMANN WF PROFILE

- PARAMETER: WHEEL TURNING MORE FREQUENT ON 1:40 PROFILE

REQUIREMENT

GAIN MORE KNOWLEDGE ABOUT ACTUAL WHEEL/RAIL INTERACTION GEOMETRY AND EFFECT OF THIS ON VEHICLE STABILITY

DEVELOPMENTS

INCREASE LONGITUDINAL STIFFNESS OF PRIMARY CHEVRONS

HIGH RATE YAW DAMPERS (SECONDARY SUSPENSION)

TO MEET SPECIFICATIONS

- 2 LOCOS IN FIELD WITH YAW DAMPERS
- STABILITY TESTING:
  - TEST AT 50,000 MILES (6930)
  - WHEEL WEAR LIMIT (6921) 60,000 MILES

BACKGROUND (CONT'D)

LONG-TERM OBJECTIVE

DEVELOP TOOLS AND CAPABILITIES FOR FUTURE TRUCK WORK

DELIVERABLES

1. REVIEW REPORT ON LITERATURE SURVEYED
2. PHYSICAL EVALUATION OF NEW CHEVRONS
3. CONTACT GEOMETRY OBTAINED FROM MEASUREMENTS
4. CORRELATION OF CONICITY AND CONTACT ANGLE INFORMATION WITH STABILITY CHARACTERISTICS
5. IDENTIFICATION OF CRITICAL CHARACTERISTICS OF PROFILE AND PRIMARY SUSPENSION STIFFNESS FOR FUTURE HIGH-SPEED POWER TRUCK DESIGNS

TIME FRAME

18 MONTHS

TASK DIVISION BY ORGANIZATION

BOMBARDIER

PROJECT ADMINISTRATION

TECHNICAL COORDINATION

LITERATURE REVIEW
- WHEEL PROFILE (CURRENT LOCO DESIGN)

MONITORING VEHICLE STABILITY
- TEST TO BE PERFORMED AT TODAY'S TOP OPERATING SPEEDS

PURCHASE AND INSTALL COMPUTER SIMULATION SOFTWARE

THEORETICAL ANALYSIS
- COMPUTER SIMULATIONS

PROGRESS, INTERIM AND FINAL REPORTS

RECOMMENDATIONS AND CONCLUSIONS

CN RESEARCH

WHEEL/RAIL PROFILE MEASUREMENTS
- DONE ALREADY
  - 2 LOCO SETS OF PROFILES ALREADY TAKEN
- TO BE DONE
  - LOCO SET OF AXLES AT 3 DIFFERENT MILEAGES
  - RAIL PROFILE: L&R, AT 2 DIFFERENT TRACK LOCATIONS

WHEEL/RAIL CONTACT PARAMETER COMPUTATION
- COMBINE DATA SETS TO PRODUCE EFFECTIVE WHEEL/RAIL CONICITIES AND CONTACT PLANE ANGLES

PARTICIPATE IN PROGRAM PLANNING

SUPPLY PROJECT SUPERVISION (WHEEL PROFILE PORTION)

REVIEW AND COMMENT ON INTERIM AND FINAL REPORTS

VIA RAIL

PROVIDE LOCO

PROVIDE SHOP FACILITIES AND MECHANICAL SUPPORT

ROAD TEST ARRANGEMENTS

REVIEW AND COMMENT ON INTERIM AND FINAL REPORTS

TDC

SPONSORING ORGANIZATION

MONITORING OF PROGRESS

HOLD PROJECT REVIEW MEETINGS

CONVENING OF TECHNICAL ADVISORY COMMITTEE

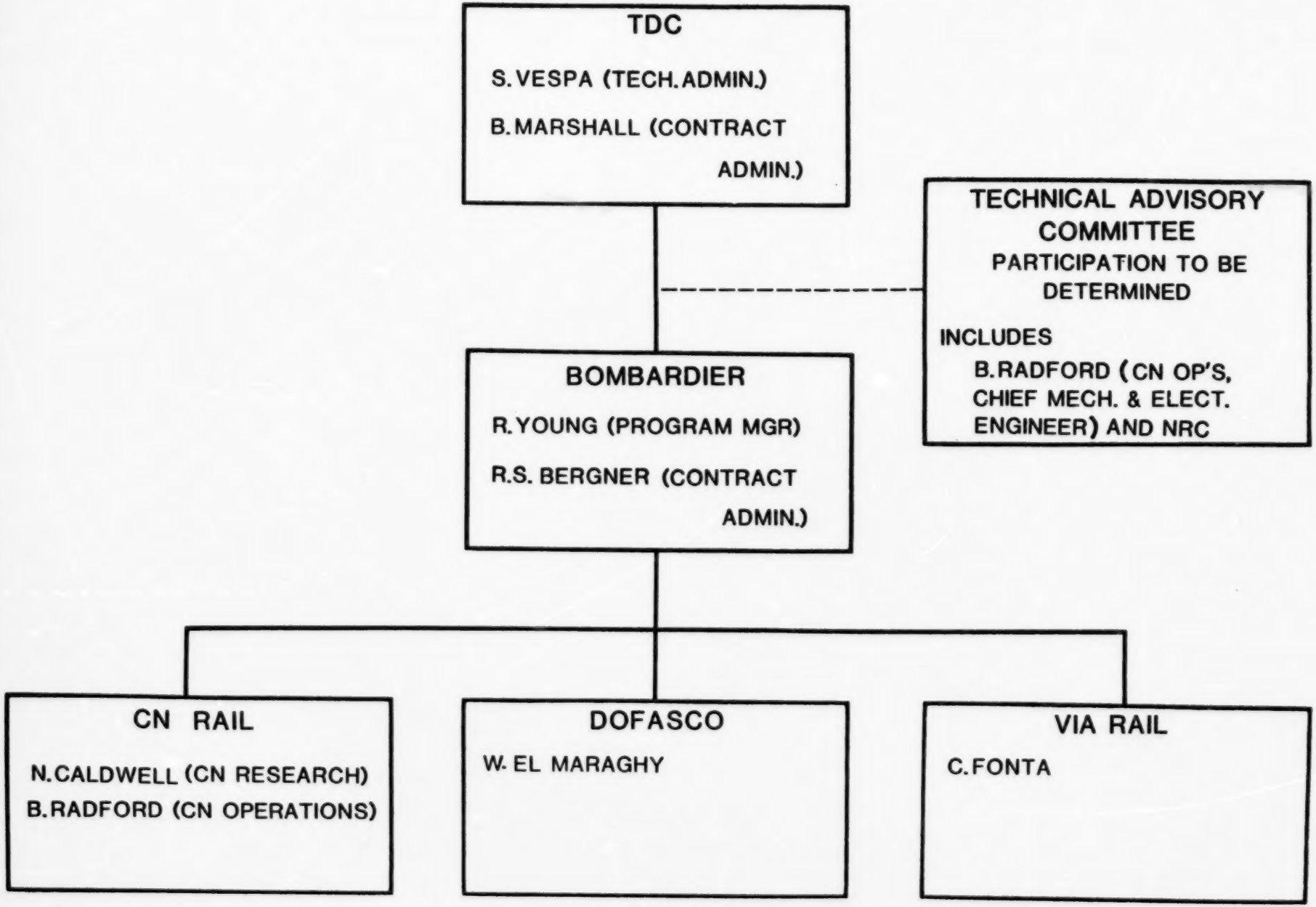
INTERIM AND FINAL REPORT ACCEPTANCE

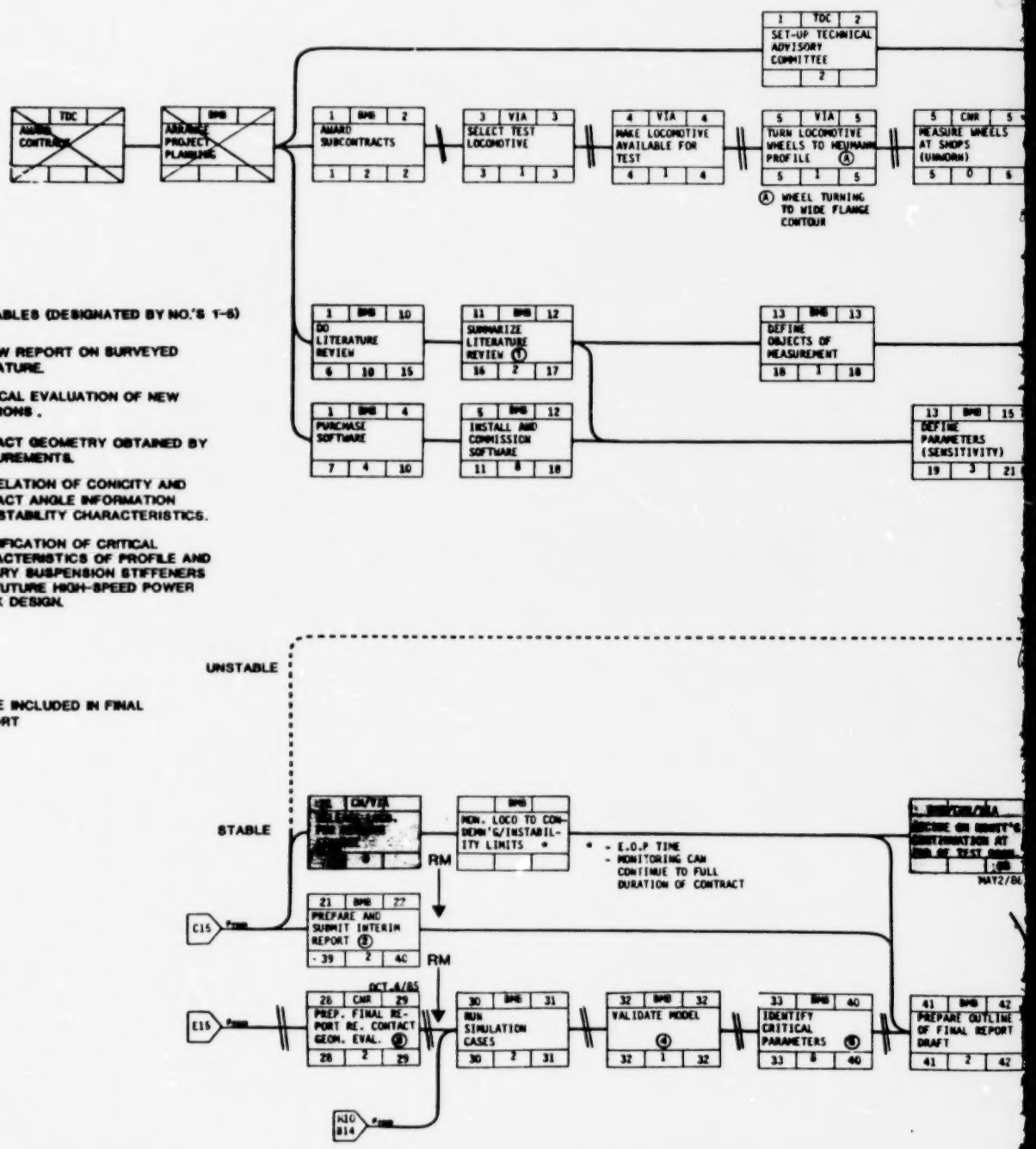
DOFASCO

ROAD TESTING
- TESTS PERFORMED AT TODAY'S TOP OPERATING SPEEDS

HARDWARE CHANGES

REVIEW AND COMMENT ON INTERIM AND FINAL REPORTS

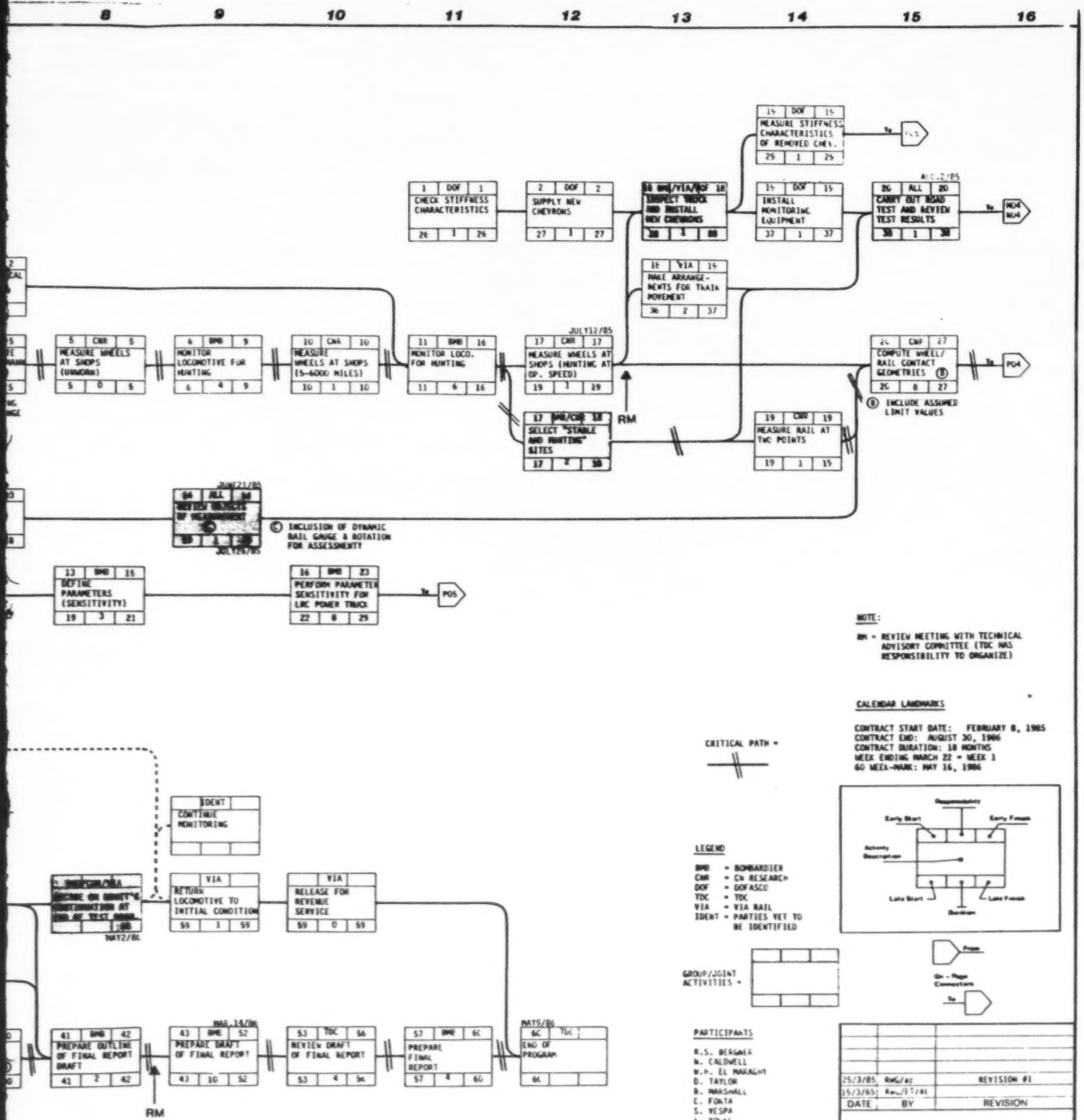

TDC
S. VESPA (TECH. ADMIN.)
B. MARSHALL (CONTRACT ADMIN.)
TECHNICAL ADVISORY COMMITTEE
PARTICIPATION TO BE DETERMINED
INCLUDES
B. RADFORD (CN OP'S, CHIEF MECH. & ELECT. ENGINEER) AND NRC
BOMBARDIER
R. YOUNG (PROGRAM MGR)
R.S. BERGNER (CONTRACT ADMIN.)
CN RAIL
N. CALDWELL (CN RESEARCH)
B. RADFORD (CN OPERATIONS)
DOFASCO
W. EL MARAGHY
VIA RAIL
C. FONTA



DELIVERABLES (DESIGNATED BY NO.'S 1-6)

1. REVIEW REPORT ON SURVEYED LITERATURE.
2. PHYSICAL EVALUATION OF NEW CHEVRONS .
3. CONTACT GEOMETRY OBTAINED BY MEASUREMENTS.
- *4. CORRELATION OF CONICITY AND CONTACT ANGLE INFORMATION WITH STABILITY CHARACTERISTICS.
- *5. IDENTIFICATION OF CRITICAL CHARACTERISTICS OF PROFILE AND PRIMARY SUSPENSION STIFFENERS FOR FUTURE HIGH-SPEED POWER TRUCK DESIGN.

* TO BE INCLUDED IN FINAL REPORT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16
CHECK STIFFNESS CHARACTERISTICS
SUPPLY NEW CHEVRONS
INSPECT TRUCK AND INSTALL NEW CHEVRONS
MEASURE STIFFNESS CHARACTERISTICS OF REMOVED CHEV.
INSTALL MONITORING EQUIPMENT
CARRY OUT ROAD TEST AND REVIEW TEST RESULTS
MAKE ARRANGEMENTS FOR TRAIN MOVEMENT
MEASURE WHEELS AT SHOPS (UNWORN)
MONITOR LOCOMOTIVE FOR HUNTING
MEASURE WHEELS AT SHOPS (5-6000 MILES)
MONITOR LOCO. FOR HUNTING
MEASURE WHEELS AT SHOPS (HUNTING AT OP. SPEED)
JULY12/85
SELECT "STABLE AND HUNTING" SITES
RM
MEASURE RAIL AT TWO POINTS
COMPUTE WHEEL/RAIL CONTACT GEOMETRIES (B)
(B) INCLUDE ASSUMED LIMIT VALUES
JUNE21/85
REVIEW RESULTS OF MEASUREMENTS
JULY20/85
(C) INCLUSION OF DYNAMIC RAIL GAUGE & ROTATION FOR ASSESSMENT
DEFINE PARAMETERS (SENSITIVITY)
PERFORM PARAMETER SENSITIVITY FOR LRC POWER TRUCK
CONTINUE MONITORING
RETURN LOCOMOTIVE TO INITIAL CONDITION
RELEASE FOR REVENUE SERVICE
MAY2/86
PREPARE OUTLINE OF FINAL REPORT DRAFT
MAY 16/86
PREPARE DRAFT OF FINAL REPORT
REVIEW DRAFT OF FINAL REPORT
PREPARE FINAL REPORT
MAY5/86
END OF PROGRAM
RM
NOTE:
RM = REVIEW MEETING WITH TECHNICAL ADVISORY COMMITTEE (TDC HAS RESPONSIBILITY TO ORGANIZE)
CALENDAR LANDMARKS
CONTRACT START DATE: FEBRUARY 8, 1985
CONTRACT END: AUGUST 30, 1986
CONTRACT DURATION: 18 MONTHS
WEEK ENDING MARCH 22 = WEEK 1
GO NEEK-MARK: MAY 16, 1986
CRITICAL PATH =
LEGEND
BMB = BOMBARDIER
CNR = CN RESEARCH
DOF = DOFASCO
TDC = TDC
VIA = VIA RAIL
IDENT = PARTIES YET TO BE IDENTIFIED
GROUP/JOINT ACTIVITIES =
Responsibility
Early Start
Early Finish
Activity Description
Late Start
Late Finish
Duration
From
On - Page Connectors
To
PARTICIPANTS
R.S. BERGMEN
W. CALDWELL
M.H. EL MARAGHY
D. TAYLOR
B. MARSHALL
C. FORTA
S. VESPA
G. YOUNG
25/3/85 RWG/ac REVISION #1
15/3/85 RWG/RT/BL
DATE BY REVISION
SPEC
NETWORK FOR
LRC WHEEL/RAIL INTERACTION
STUDY - BOMBARDIER/TDC
N° 85-0007-54